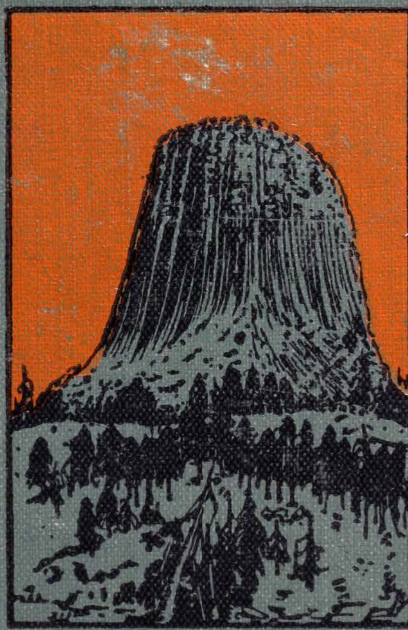
The NEW GEOLOGY



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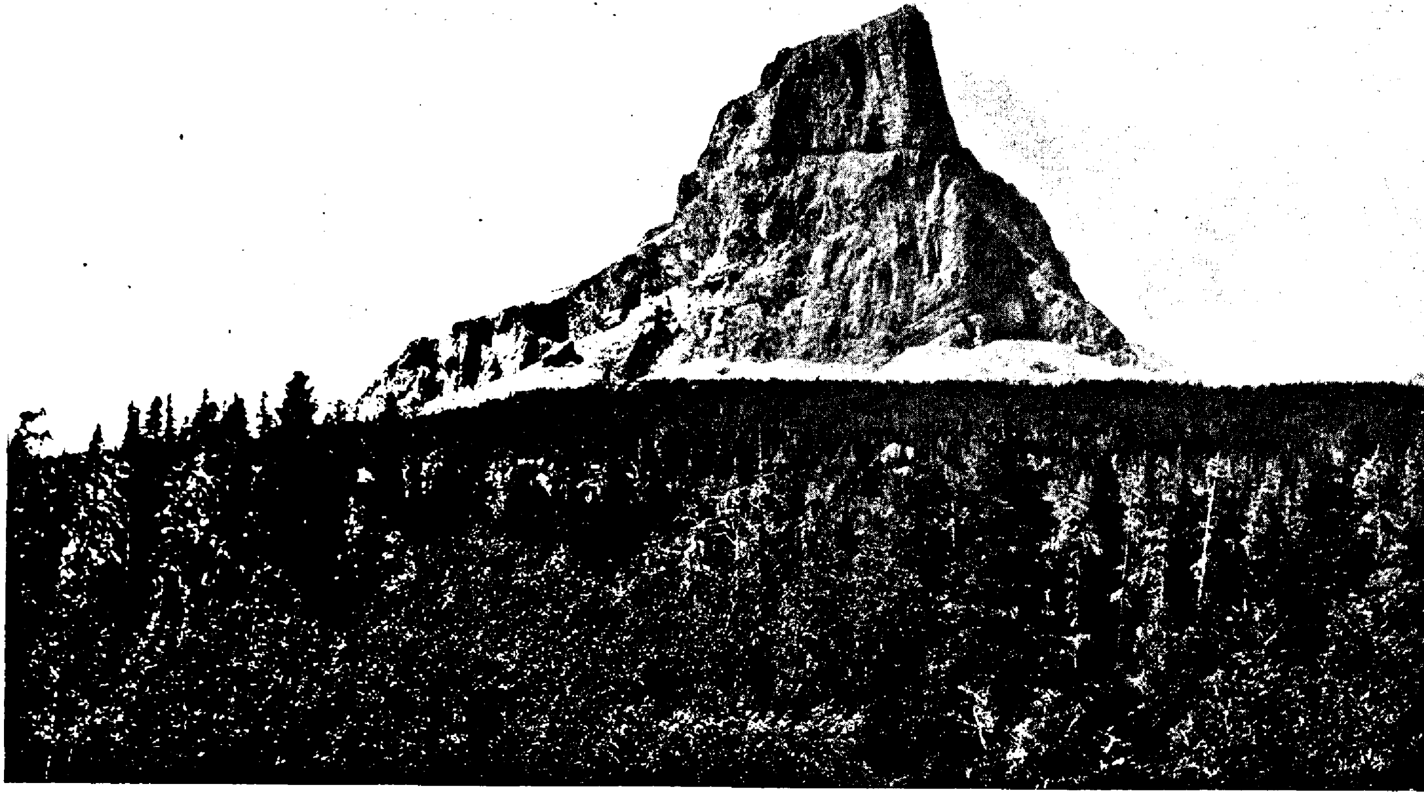

Fig. 1. Chief Mountain, Montana, from the north fork of Kennedy Creek. Algonkian resting on Cretaceous. (Willis, U. S. G. S.)

The NEW GEOLOGY

A TEXTBOOK FOR COLLEGES, NORMAL SCHOOLS, AND TRAINING SCHOOLS; AND FOR THE GENERAL READER

by

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Printed in U. S. A.

PACIFIC PRESS PUBLISHING ASSOCIATION
MOUNTAIN VIEW, CALIFORNIA
Kansas City, Missouri — Portland, Oregon — St. Paul, Minnesota
Brookfield, Illinois — Cristobal, Canal Zone

PREFACE

In various ones of the natural sciences, it has often happened that the theories of one generation have become the dogmatic doctrines of the next. Fortunately, in such sciences as physics, chemistry, and bacteriology, theories are usually short-lived, unless they rest on a solid basis of facts. Fortunately also, the prime postulates at the basis of most of the natural sciences are merely those basic truths of experience and common sense which are capable of being checked up by reality almost at an instant's notice.

In geology, however, we have long labored under the handicap of having several wide-sweeping assumptions lying at the very threshold of our investigations; and these assumptions have shown a phenomenal tenacity of life, because they were of such a nature that they could not readily be checked up by either experience or experiment. Such were the theory of the molten interior of the earth, the theory of uniformity, and the theory of a succession of life in a definite order all over the globe. For many decades, these assumptions and their many corollaries have not only pervaded all the literature of the science, but have also strictly limited observers in what they *ought* to find in their investigations, just as truly as the scholastics of the Middle Ages felt limited always by what the church had defined as truth. Of late years, it is true, the first two of these three primary assumptions, long venerated as dogmas, have been partly shaken off; for the theory of the molten interior of the earth has fallen into disrepute, and instead of a dead level of uniformity, recent geological theory has been verging more and more toward a sort of cyclical catastrophism, periods of uniformity being considered as having alternated with other periods of greatly accelerated geological action. But the strictly definite order of successive groups of plants and animals has imperceptibly passed out of the position of an assumption, and is to-day treated as the most firmly established dogma of the whole science. And few of the modern students of geology have ever given sufficient attention either to the history of this idea or to its logical foundation to realize that this historical outline of the alleged successive forms of life is *still only an assumption,* and has already become an incredible assumption, in view of certain facts which have come to light in recent years.

When a man trained in any other mental discipline takes up a modern geological report of some particular locality, or dips into a discussion of the age of a particular set of beds, he is at once amazed at the easy confidence with which the geologist asserts a knowledge of the geography of the long-vanished age which is under consideration, with just as definite a knowledge of the migrations of the various types of animals, and the exact time (relatively) in the chronology when certain types of life appeared or disappeared. And he begins to ask in his own mind, "How much of this story is actual *fact*, and how much is merely imagination or hypothesis?" If he perseveres and attains to a more extensive acquaintance with the science as it is taught and written about to-day, he is not likely to have his query answered, but on the contrary, is almost sure to arrive at the conviction, sooner or later, that geology is a very profound subject, and the underlying principles and methods are deep secrets known only to the initiated; all dabblers must be content to take without question the dicta of experts in these matters.

The name of the present volume is not meant as a challenge; but it is meant as the designation of a method which the author believes is here employed for the first time in a geological textbook. Whether the author has always succeeded or not, the effort has at least been made to *keep facts and theories clear and distinct;* and where alternative hypotheses are possible and permissible, these alternatives are openly stated, and the reader is advised to take his choice. True, the author has often felt free to state a line of argument in favor of that hypothesis which he considers the more reasonable. But it is supposed that even the beginner in the science will acquire a better appetite for more of the subject, and will be more mentally alert to discriminate between the true and the false in the way of theories, if he is not always spoon-fed with those theories which in the minds of most teachers of the science have already crystallized into infallible dogmas. In the first part, and, indeed, in all the body of the work, the great problems of the science have been held steadily before the student *as problems to be solved,* not as questions already settled by all the experts in the science. Only in the concluding section, when all the leading facts are already before him, has the student been asked to decide between the conflicting hypothetical solutions. If such a method should appear like a new thing under the sun, so far as geological textbooks are concerned, this very fact might suggest to the thoughtful person the urgent need of such an attempt at reforming the method of teaching this subject. And the author

is satisfied that, whether or not the present work is successful as an effort thus to reform the teaching of this science, such a reform must inevitably come sooner or later.

Why should any apology be needed here for bringing in the hypothesis of a great world catastrophe to account for some (an indefinite amount) of the geological changes? Its rival, the theory of uniformity, has so long been in vogue that we are all inclined to forget that it also is *only a theory;* and that if this ancient alternative, a great world catastrophe, will more satisfactorily explain some of the phenomena, a true scientific induction ought not to have any settled prejudice against it which would continue everlastingly to rule it out of court. In the opinion of the present writer, the latter method has prevailed about long enough; and this volume has been prepared in the belief that if these two rival theories are impartially examined in contrast in the light of all that modern science has revealed to us, the decision must inevitably be in favor of that hypothesis which has been furnished to science ready-made by the oldest documents of the human race, to say nothing of the concurrent traditions of every people on earth.

Since the publication of the writer's "The Fundamentals of Geology" (first edition, 1906), there has been a growing demand for a textbook based on the principles there stated. The presentation of such a treatise, however, involving the actual reconstruction of the whole science, has been no easy task. The present volume is only a tentative effort along this line; and the author would esteem it a great favor if the critics who may read it, and the teachers who may use it, would report to him any mistakes of fact or any faulty methods of description which they may observe in it, so that these may be corrected in subsequent editions. The first edition of any pioneer work of this kind, which endeavors to reconstruct the whole body of so highly developed a science as geology in many of its aspects now is, can not fail to be in many respects a crude affair; but the readers of the book can materially assist the author in making subsequent editions more in keeping with his high aims to build only on that solid ground of nature which makes for aye.

The notable works of Suess and Howorth have largely furnished the inspiration for the present volume, these works being, so far as they go, founded on true inductive principles. The present writer must ever consider these two men as his masters; but in addition, many other prominent authors and teachers of the science have contributed varying amounts of help. Yet the author hesitates to mention their names here, for fear such

a mention might be misunderstood as an effort to make these fellow workers partially responsible for the views here set forth. For these views he wishes to take the entire responsibility,— a responsibility, however, which many intelligent people in other lines of intellectual work will not consider altogether a disgrace. At least, the volume has not been hastily thrown together; for it has occupied much of the time of the author for over ten years. And if the teachers and students who may use it acquire therefrom a greater interest in the great book of nature, and develop a greater ability to discriminate between facts and theories regarding the earth and its history, this book will have served the purpose of

THE AUTHOR.

College View, Nebraska, March, 1923.

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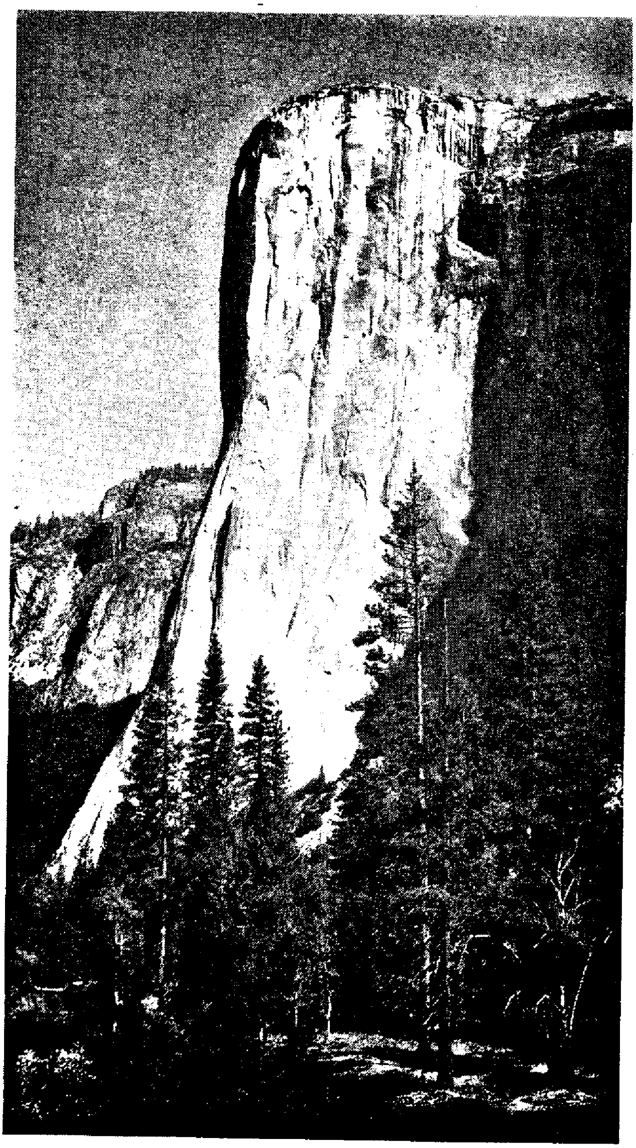


El Capitan, Yosemite Valley.

INTRODUCTION

Problems. Geology is that branch of natural science which seeks to solve the great problems relating to the earth,—its structure, the present behavior of its various parts, and its physical and biological history.

No study of the plants and animals now living on the earth can be of much educational value unless this study of the modern forms is supplemented with a similar study of the plants

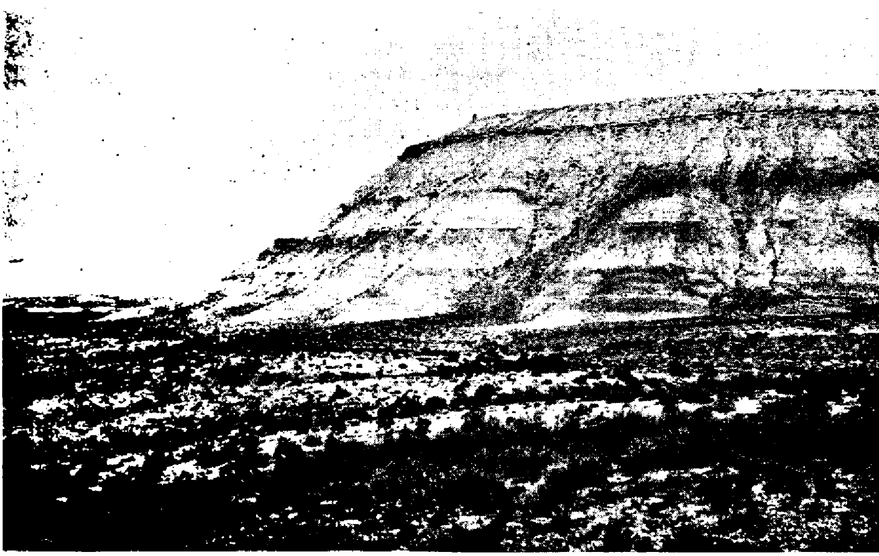


Fig. 2. Bluff of Wasatch (Tertiary) rocks about one mile west of Hamilton, Wyoming. Gastropods and pelecypods (sea shells) are abundant in the shelf near the middle and at the top. This locality is now about a mile above sea level, and a dry desert. What has made the change? (Lee, U. S. G. S.)

and animals of the past. And no knowledge of the present distribution of land and water, and of the present-day action of air, water, and temperature, can be complete without a knowledge of the conditions regarding these matters that have prevailed in the past. Geology includes all these subjects; for though it is chiefly concerned with the physical changes that have taken place in the earth, the records of which have been stamped in the rocks during the very processes of these changes, these fragmentary leaves from nature's diary are extremely intricate documents, and can be successfully read and put together into an intelligible and truthful narrative only by the help of those tombstone inscriptions, found almost everywhere, in which the buried dead, in writing their own epitaphs, have

also unconsciously recorded the sad story of the world in which they lived, which was destroyed and changed into the world as we now find it (Fig. 2).

Geology thus deals with the earth's structure, its present changes, and its past changes, or its history. The study of geology involves as complete a knowledge as possible of most of the other sciences; for it builds on the perfected knowledge of the many physical and biological sciences which have been developed in modern times. It is essentially a science of *problems regarding the past;* and a correct solution of these problems demands not only as complete a knowledge as possible of all the potentialities of all the constituents of the earth, but demands also a peculiarly judicial attitude of mind, one that will not form snap judgments on scanty and insufficient data, and that will nevertheless not hesitate to assign causes competent to explain all the phenomena with which we have to deal.

Until quite recently, geologists have often thought they had disposed of a problem when they had merely pushed it back so far into the shadow of the remote past that its conditions could no longer be clearly seen. But this prodigal demand on time is just as unscientific as the prodigal use of many causes when one would be sufficient. A truly scientific induction regarding the earth's history will seek to decide, not how the changes of the past *may* have occurred, but how only they could have occurred. Moreover, geology is in no sense concerned with the origin of things — either with the origin of the earth, or with the origin of the plants and animals upon it. In other words, *geology is not a cosmogony,* though it has often been treated as a cosmogony by some who did not understand the true limits of scientific research. It deals with what appear to be the ruins of a world, certainly not with its origin; yet a sound philosophy may take up the investigation where geology leaves off, and by building on the results obtained by geology, may be able to tell us something very important regarding the origin of things.

Former Methods of Interpretation. Beneath the soil and water on the surface of the earth, we find everywhere a substructure of hardened rocks. In many places, as seen in the rocky cliffs bordering many valleys, in the ledges about the tops of mountains, and in the cliffs along the seashore, these hard rocky ribs of earth's framework are found protruding through the shallow soil, and revealing the layers, or *strata,* of which they are composed, or sometimes showing a crystalline structure without distinct layers.

The rocks beneath the soil generally lie in beds. These beds may be a few inches or many feet thick; but no matter how great their thickness, they are usually spread out over one another in successive layers. In the early days of the science, it was supposed that each particular *kind* of rock, such as lime-

stone, sandstone, or shale, was always to be found in the same position relative to the others; and hence it was said that they all originally encircled the whole globe like the coats of an onion. When this was found to be contrary to fact, the remains of plants and animals embedded in the rocks, and known as *fossils,* were fixed upon as furnishing the true index of the age of the rocks and of their history, as compared with other rocks elsewhere. Thus for several decades, or for over a hundred years, the rocks have been named and classified according to the fossils which they happen to contain. According to this view, similar fossils, wherever found over the world, are regarded as of approximately the same age, and dissimilar fossils are regarded as of different ages, the various typical kinds of fossils, which it is supposed successively occupied the earth, having been worked out in very elaborate details from scattered localities all over the earth. The arrangement of these various typical fossils into what is regarded as a true historical order, has been the chief occupation of geologists for a century; but this arrangement has always been a *purely artificial arrangement,* although it was founded on the alleged fact that wherever they occur, they occur in this same relative order. Thus we have a sort of biological onion-coat theory, based on the assumption that each great assemblage of life found in any particular set of beds represents a group which at some remote time occupied the world exclusively and universally, this group in its turn giving place to other forms of a different type. Of late years, however, this "life-succession theory," as it is called, has been found to be untrue, and impossible as an interpretation of the facts of the rocks; but it is still believed by most geologists, and is still taught in most of the textbooks. It has always been merely a theory or an assumption, as a means of interpreting the facts of the rocks; though it is often treated as if it were the *only* possible interpretation of these facts.

All the stratified beds, or those containing fossils, are of quite limited extent, varying from a few square yards or a few acres to a few hundred square miles in area. Sometimes these beds, when followed out on the sides, are found to end abruptly; sometimes they split up into several distinct beds and dovetail into other beds; and sometimes they change into beds of very different texture, or into beds containing distinctly different kinds of fossils. Thus the biological onion-coat theory is just as physically absurd as was the mineralogical onion-coat theory. Moreover, the various kinds of fossils, which were so long thought to be found only in the same relative order all over the

globe wherever they occur, are now known to occur in practically every conceivable order, or at least in many orders directly contradicting the alleged standard order, just as the various kinds of sandstone, limestone, and shale may occur in any relative order whatever.

When it was supposed that the different kinds of sedimentary material were spread around the globe universally as precipitates from a universal ocean, and that they always preserve the same order relative to one another, just as real onion coats do, it was reasonably supposed that they must represent a true historical succession, just as the successive rings on a pine or a maple show a real succession. Thus, only one kind of rock, it is said, was formed at any one period in the world's history; and after this had ceased to be formed, another and totally different kind began to be produced. Hence it was axiomatic and inevitable that these various kinds of rocks must represent a true succession in time; for, of course, unless disturbed since their formation, the rocks now found at the bottom of a given series must be the oldest, and those above must be younger; for when first formed, they must all have been spread out flat, as sediments or precipitates are now deposited.

But when, with further knowledge, it was realized that the various kinds of rock were never universal, never of more than very local occurrence, or *provenience,* as it is technically called, and when it was discovered that the various rocks did not always occur in the alleged invariable order, then the mineralogical onion-coat theory had to be given up. In an exactly similar way, when it was realized that the various fossiliferous beds could never even originally have been universal, never more than of local occurrence, and when it was discovered that in numerous and important instances, the fossiliferous beds occur in many orders of sequence very different from the alleged invariable order, then the biological onion-coat theory also had to be given up. The history of the refutation of the one theory is the counterpart of the history of the refutation of the other.

But it took a good many years to shake off the mineralogical onion-coat theory entirely; and it seems to be taking fully as long a time to get rid of the biological onion-coat theory. The former persisted well along into the first third of the nineteenth century; and the latter is still cherished by many people, although its refutation has now been before the scientific world for nearly twenty years, or almost from the beginning of the twentieth century.

If none of the fossiliferous beds are universal, but all are of merely local extent, how absurd it is to think of proving from them that only a certain limited few of those animals and plants which they contain were alive at a certain period in the world's history, and that after these became extinct, another set of living forms succeeded and in turn became universal! We may assume this evolutionary succession of life, if we wish, as a working hypothesis, and see if we can arrange the fossils to fit it; but we should always remember that it is *merely a theory*, and should also remember clearly that we *can never prove it* as a real scientific fact, even after we have arranged all the fossiliferous deposits of the world to fit it; for this arrangement of the fossils must ever be a purely artificial scheme, with never anything more than a constructive existence. We could arrange all the books in a library according to their titles, from A, B, and C, down to X, Y, and Z; but it would be a purely artificial scheme, and to say that this arrangement proved that the books arranged under A, B, and C must have been written and published long before those arranged under X, Y, and Z, would be absurd.

Time. It is a very ancient obsession in geology, that these various deposits of rock must represent successive long ages. Obviously there is in any given locality a plain record of a succession in time, since these beds could not all have been deposited at once. The difficulty has always been in trying to find some method strictly scientific and logical whereby these *local* events could be extended and expanded into events of world significance, and thus to formulate a reliable world history from the records of the rocks in a few limited localities.

On the one hand, the scientific experience of nearly two centuries seems to prove that there is no possible way to differentiate these deposits from one another in respect to actual age, so as to assign some of them to one age and some to another age long subsequent to the first. For there is always this difficulty from the point of view of real science, of *getting back of the conditions known to experience*, with a world fully stocked with plants and animals, and with very diverse kinds existing together, as in our present world, the only world of which we have direct knowledge. Indeed, it is necessary to assume a supernatural knowledge of the past, in order to be sure that when certain types of fossils, such as the trilobites or the dinosaurs, were living in certain localities, certain other types, such as belemnites, or ammonites, or elephants, were *not* yet in existence in some distant locality or localities.

On the other hand, we can never ignore the *alternative hypothesis*, that these various deposits represent merely the ruins of a world well stocked with plants and animals, which, by a series of rapid catastrophic changes of no very great duration, was transformed into the world as we have had it since historic times.

Thickness of the Strata. Another point growing out of these former misunderstandings needs to be explained; namely, the total thickness of the fossiliferous strata. When it was first assumed that the different fossils represent successive ages, it was soon discovered that in no particular locality could even a majority of the successive strata be found all together one above another. The total thickness of stratified rocks found piled up in any one locality is never more than a few thousand feet. And any such local succession of beds never contains more than a very few of the total number of the typical fossil types; usually not more than parts of two or three "systems," as they are called, are found together in any particular locality. Hence, in following out the popular theories, it became necessary to bring very many widely scattered deposits together, and to imagine the beds of one locality superimposed upon or piled up on top of those from other localities, in order to complete the whole series of beds alleged to have been made in the successive ages. And by thus piling them one on top of another from various separated localities, it has been said that the total thickness of the stratified deposits amounts to about 30 miles. But this is not a scientific method of procedure. The total thickness of the stratified deposits in any particular locality is all that any true scientific method can reckon when speaking of the total thickness of the water-formed rocks; and this is never more than a few thousand feet.

Probably two or two and one half miles may be taken as a safe maximum; while in the majority of places it is probably less than one mile, and in thousands of places all over the earth it is only a few hundred feet, or even less. Thus we may say of the total thickness of the strata, as Mark Twain said of the report of his death, that it has been greatly exaggerated.

Characters of the Stratified Rocks. In penetrating into the earth, we always find that the stratified beds rest upon others, such as granite or schist, which are not stratified, but crystalline in texture. These crystalline rocks are also interesting and important geologically, and often contain valuable minerals or ores. But they are obviously not connected with the stratified rocks in their origin, and probably represent a previous period of the world's history, before the stratified rocks were formed. As to the character of the rocks constituting the great mass of the earth

deep down beneath the limits of scientific observation, we can only conjecture. The surface parts of the crystalline rocks may furnish us some materials for comparison, and rock masses which have come up from unknown depths through volcanic vents and fissures may be supposed to furnish us with samples of material from lower depths than we have access to in any other way. Still, as volcanic action is now supposed to be comparatively shallow, we really have no means whatever of knowing what the great mass of the earth is like.

The various rock masses teach us many things by their structure and arrangement. Most of them give evidence that they were made of mud, sand, or gravel, much like our modern mud, sand, and gravel. But there are two marked differences between the ancient and the modern deposits. Our modern rock-forming materials, derived largely from decomposed rocks, and carried down by rivers, to be arranged in beds on the bottom of some lake or ocean, are always more or less of a *heterogeneous mixture,* though sand, or gravel, or mud may so predominate as to furnish a convenient name for the whole. In contrast with this, the ancient limestones, slates, or sandstones often stretch out in great sheets, miles on miles in area, without containing anywhere a corresponding mixture of particles. Hence these ancient deposits could not have been formed exactly as the corresponding sedimentary beds are now being formed, though we know that they must have been spread out by water, in most cases by the waters of the ocean.

The so-called drift beds, with some rocks classified as Tertiary, and a few other surface rocks, often show a considerable mixture of particles, and are thus much more like the modern deposits, and in marked contrast with the great majority of the geological formations.

But the second point of contrast between the ancient and the modern deposits is with reference to the fossils which they contain; and in this respect, the contrast is even more marked. In our modern deposits, the remains of plants and animals are scanty in numbers and very poorly preserved. But the ancient rocks are often full of the remains of once living organisms, like trenches after a battle, many of these remains being in an astonishingly perfect state of preservation (Fig. 3). Hence, by their fossil contents, even more than by their lithological structure, the ancient strata seem to proclaim that they were generally formed in some way different from the methods of rock formation prevailing in our modern world. But only as we correctly interpret the record can we hope to frame a true induction regarding the way in which these ancient deposits were made.

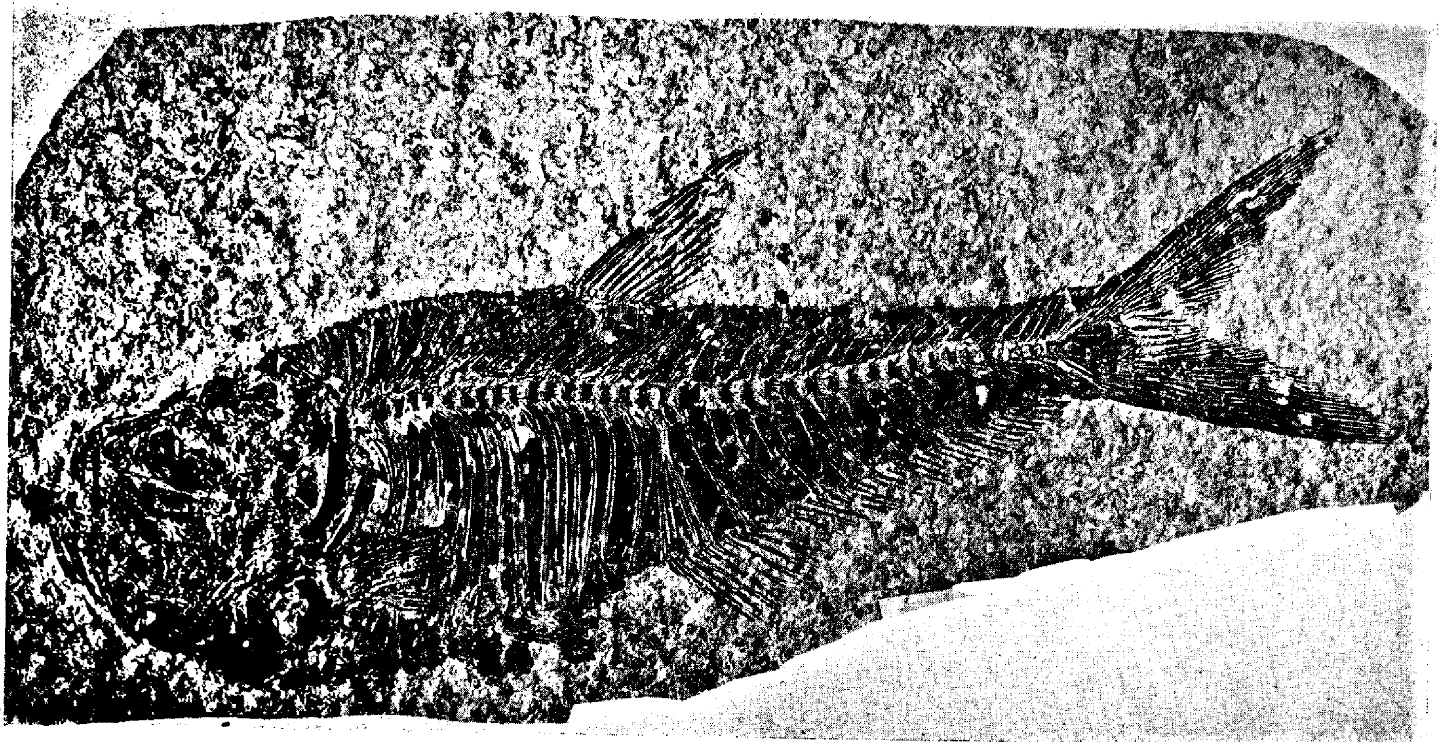


FIG. 3. *Diplomystus dentatus*, from a quarry in Grand River (Tertiary) formation, Western Wyoming. All the parts are well shown. (Lee, U. S. G. S.)

In many places, the rocks, after having been piled up to a depth of many hundreds or thousands of feet, have been broken open by great cracks or fissures; and in some instances, these fissures have been filled with melted rock material which has come up from some heated region in the depths below. Some instances of this sort have been observed to occur in modern times; and they are always accompanied by more or less violent earthquake movements. And if we assign a similar cause as the explanation of the much larger fissures and ejections of heated rock materials which have occurred in the past, the records of which are plainly visible in the rocks here and there, we must suppose that the earth went through some frightful convulsions *after* most or all of the fossiliferous strata were laid down. For in some instances, these fissures involve *all* of the strata in the locality where they occur, and the ejected materials have been poured out on top of the ground. In other instances, these fissures involve only a certain lower depth of the strata, and the ejected materials have been laid out with other sedimentary materials now lying above them. In this instance, we may suppose that this fissuring of the lower beds and the ejection of molten materials may have occurred beneath the ocean waters, while the sedimentary beds were in course of deposition; or that this ejection of liquid material took place while the rocks were above the waters, and that afterwards the whole set of strata were submerged and other beds deposited upon the ejected layers; or that these liquid materials forced their way up through some of the beds, and then extended themselves as wedges between these beds and those lying above them. In each particular instance, we must decide on the exact method of formation of these rocks as best we can, according to the evidence in that particular instance.

Many sets of beds have evidently been so disturbed by earth movements of some character that they are no longer horizontal, as at first laid down, but more or less tilted and inclined, as if the two sides of the beds had been pushed together by some enormous lateral pressure, or as if the supporting foundation had given way under some parts while remaining in place in other parts (Figs. 159, 160). This tilting and contorting of the strata is much more noticeable in mountain regions than elsewhere, because the outcrops of the beds are there much more exposed; but it is quite probable that the beds even in a seemingly level country would be found thus similarly tilted and faulted, if we could examine their structure under the mantle of surface beds or soil (Fig. 156). The real causes of these disturbances in the strata after they were laid down, are not well understood. But it seems

certain that no such causes are now operating anywhere on earth; for while earthquakes are common enough, and faults and breaks in the strata are occurring every now and then, nothing at all similar to this flexing of the strata has ever been observed since the beginnings of scientific observation.

Lastly, many beds which were originally laid down in a soft state, by water, as incoherent sand or mud, have since become hardened and even crystalline over vast areas, an originally stratified rock mass having thus entirely lost its visible stratification, being now changed into a mass of granite or slate. This change of texture has been brought about by pressure and heat, the friction attending the flexing or disturbing of the strata having often generated sufficient heat to crystallize the entire mass of a mountain.

The changes enumerated are some of the chief forms of recorded events in the history of the earth which geology is called upon to read and interpret; and it is evident, from even this cursory glance at them, that these records are extremely intricate, easily misunderstood and misinterpreted, and that they can be correctly read and interpreted only after the most painstaking study and an impartial estimate of all the evidence available.

Modern Methods of Interpretation. But the chief scientific source of information concerning the history of the globe, is the remarkable array of facts which may be gathered from a careful study of the shells, corals, leaves, bones, or other remains of plants and animals, which are often found embedded in the rocks, all such remains or relics being known as *fossils* (Latin, *fossilis,* something dug up). For, just as a coroner, by a careful study of all the circumstances in which a dead body is found, can often arrive at a correct idea of the way in which the man died, and of at least the circumstances in which he lived immediately before death, so geologists, by careful study of the fossils, may not only tell something of how they came to be buried in the rocks where we find them, but may even reconstruct, with a degree of accuracy and completeness, the conditions of climate and the other factors of the environment in which they lived, and thus may arrive at a more or less distinct picture of what that ancient world was like before these great changes took place.

As a careful study of the human body in health under normal conditions is indispensable to a coroner in dealing with a body in death under perhaps very abnormal conditions, so a knowledge of the present everyday changes in earth, air, and water is a prerequisite to a correct interpretation of the message inscribed in the ancient rocks. But just as a coroner may, by unmistakable evi-

dence, be compelled to believe, in spite of himself, that something out of the ordinary has happened and that a murder or a suicide has been committed, so may the geologist be compelled, by cogent evidence, to believe that the ancient deposits in the earth were not laid down in the quiet, regular manner in which beds of clay, sand, and gravel are now being formed, but that something of a wholly abnormal nature must have taken place in the past. To perform a truly scientific or inductive investigation of the rocks, based on the evidence presented, we must not come to this investigation with the bias or prejudice that only the normal or present-day rate of change has always prevailed in the past, as Lyell and most succeeding geologists have done. We must hold an open mind on this point, until all the pertinent evidence has been examined; for one of the most important of the problems confronting us is to decide whether or not the tools of nature have always worked at the same rate and in the same manner as at present.

Divisions of the Subject. From the foregoing outline, we may see that the objects of the science of geology are many and varied. They may be conveniently grouped under five leading divisions, as follows:

1. To consider the earth as a planet, and in its general surface features.
2. To study the composition and character of the various rocks, and their arrangement in rock masses.
3. To ascertain the present behavior of the forces of nature, and their potential possibilities; to see how rocks are now being made, how fossils are now being formed, and to determine, by comparing the ancient formations with the modern ones, what sort of elemental action must have produced the ancient deposits.
4. To note where the various kinds of fossils are found, and in what condition; to compare them with their living representatives; to classify these ancient forms of plants and animals in some systematic order like that adopted for the living forms; and to formulate whatever lessons these ancient remains may have to teach us.
5. To study the history of geological interpretation; to group together some of the great outstanding facts of the science, for the purpose of framing a true induction from them all; and to study the bearings of the facts of the rocks upon the problem of the origin of the earth and of its inhabitants.

Hence we may study the science of geology under the five principal branches:

I. PHYSIOGRAPHIC GEOLOGY,— treating of the general aspects of the earth's features.

II. STRUCTURAL GEOLOGY,— treating of the rocks of the globe, their constituents and characteristics, and their arrangement in masses.

III. DYNAMICAL GEOLOGY,— treating of how rocks are now being made or modified, and by comparison with the anciently formed rocks, showing how the latter must probably have been produced.

IV. STRATIGRAPHICAL GEOLOGY,— treating of the fossiliferous strata, their classification and location; the comparison of their fossils with the living forms; and some of the more obvious lessons to be learned from such a comparison.

V. THEORETICAL GEOLOGY,— treating of the true scientific methods of studying the ancient strata; and seeking to formulate a safe and accurate conclusion regarding the past of our earth, based on all the evidence at our disposal.

Part I — Physiographic Geology

CHAPTER I

The General Features of the Earth

Introduction. What do we know about the history of the earth? Or what do we know about the origin and antiquity of man and animals and plants now living on the earth? The answers to these questions are inextricably bound up with our knowledge and our interpretation of the various earth processes now going on,— the action of the air, the water, and the internal forces of the earth. What are these earth forces doing in modern times? Have they always acted as we now observe them acting?

In attempting to solve any problem, we must first have the facts in the case,— all the facts we can get which bear on the subject we are considering. In the present instance, we need first to get a broad general view of the earth as a whole, and as related to the other members of the solar system. We shall then need to examine briefly the earth's surface features.

These two classes of facts may be included under the general head of "Physiographic Geology."

The Earth as a Planet. The earth is one of a group of planets all of which revolve around a huge central sun. This group of planets revolve in what is very nearly a common plane of revolution, and each planet revolves not in a perfect circle, but in an ellipse, with the sun in one of the foci; though in the case of the earth, the variation from a perfect circle amounts to only about 1.5 per cent of the diameter of the orbit. The earth rotates on its polar axis once in 24 hours, while revolving around the sun in about 365¼ days, its polar axis maintaining a constant inclination to the plane of its orbit of about 23½°, this arrangement being the cause of the varying seasons in the earth's Northern and Southern hemispheres.

Outside our solar system are great numbers of other bodies, many of which we can see on a clear night, and which we call the *stars*. Most of them are suns similar to our own; but they are so very far away that if each of them has a family of planets around it, these planets could not possibly be visible even with the most powerful telescopes. A brief statement of the results obtained by reducing the universe to a scale, will make this point clear.

If we let one millimeter represent 10,000 miles, our sun will be about the size of a baseball, and the earth, with its mere 8,000 miles of diameter, will be represented by a small dot 8/10 millimeter in diameter, some 9.3 meters away from the baseball, or about the distance across an ordinary

schoolroom. Mercury and Venus would be represented by smaller dots intermediate in distance between the earth and the sun; but the major planets are farther off, Jupiter being about the size of the end of a chalk crayon and some 160 feet away, while Neptune would be much smaller than this and situated nearly a fifth of a mile away. But on this same scale, Alpha Centauri, the nearest of the fixed stars, would be less than a foot in diameter and *about 1,600 miles away.* On this scale, only 19 of the fixed stars known to us could be placed on the earth at all. More than half of

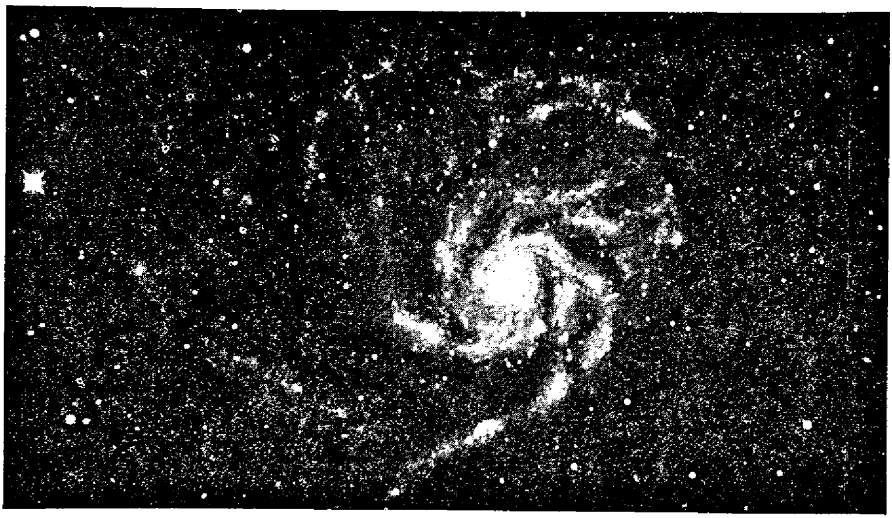


FIG. 4. Spiral Nebula in Ursa Major, known as Messier 101. (From a photograph taken at Mount Wilson Solar Observatory.)

them would have to be set farther away than our moon. This helps us to realize that our solar system is very much alone by itself, and also that our little speck of a world is quite insignificant in point of size.

The Nebular Hypothesis. But, insignificant as it may appear, this earth is the subject of our present study; and we do not have a sufficient amount of exact knowledge regarding the other bodies of the universe to help us very much in our study of the earth.

Much useless speculation has been indulged in, regarding the origin of our solar system, these speculations being professedly based on the large number of points in which all the members of this system resemble one another in their rotations and revolutions. Kant, in 1755, and Laplace, in 1796, proposed what has since been known as the *nebular hypothesis,* to account for the origin of the present solar system.

A vast nebulous mass with a very high temperature was assumed to have existed, and to have extended out far beyond the present orbit of Neptune, the outermost of the planets. It was assumed that this vast nebulous mass

revolved about a gradually condensing nucleus or sun, and that under this revolution it gradually assumed a disklike form. It was supposed that, in process of time, various successive equatorial zones or rings were formed in this rotating mass, these rings finally condensing into the various planets, the sun being the condensed central nucleus, and still retaining much of its original heat, though the planets have lost most of theirs. On this hypothesis, our earth must have passed from the gaseous to a liquid state, and finally into a solid.

Objections. But fundamental objections to this hypothesis have been brought forward from time to time, until now we may safely say that it has no longer any standing among men of science, though it still survives in some belated textbooks, and is still quite popular among people who have a slight acquaintance with scientific facts. Two fundamental objections to this hypothesis may be stated as follows:

1. If the total mass of the solar system once revolved as a unit and condensed, it would gain in its angular velocity of rotation toward the center, and finally its equatorial belt would reach a critical point of speed where the outward centrifugal force would balance the inward gravitational force. From this point of time, this whirling material could not any longer converge toward the center, but would be left rotating at about this definite distance from the center. The remainder would continue to condense and accelerate, till it also was left behind. This much would seem to be in accord with the facts as we see them. But contrary to the working out of this proposition, the giant planet Jupiter seems to have acquired most of the bulk of the planetary matter of the system, and also most of the speed of rotation; for it exceeds the collective mass of all the other planets in the proportion of 5 to 2, and although so huge in size, it rotates on its axis in about 9 hours and 55 minutes. All the planets between it and the sun are almost negligible in point of size when compared with it.

2. According to this hypothesis, the sun ought to be rotating very swiftly, and ought to be much flattened in form, or highly oblate. On the contrary, *it rotates quite slowly, or once in about 25 days,* and this slow speed allows it to be almost spherical in form. According to the laws of celestial mechanics, this condition of the sun proves that it could never have revolved with more energy than at present; hence the original nebula, if it included the planets, could never have revolved as a unit. Therefore the material composing the planets must always have been separate from the sun; and on this basis, it is impossible to suppose that the solar system originated in the way suggested.

In addition to these *two fundamental objections*, the force of which can only be appreciated by those with a wide knowledge of celestial physics and of the molecular behavior of gases, other objections to this hypothesis may be stated as follows:

3. No ring-shaped solar nebulæ have yet been discovered, nor anything resembling such a form. (Charles Schuchert, "Textbook of Geology," p. 511.)

4. If the planets had originated from a system of rings, according to the theory, they ought now to be found rotating in a direction opposite that of the parent body; but instead, they rotate in the same direction as the sun.

5. The satellites should revolve about their planets in the same direction in which the planets rotate on their axes. On the contrary, the ninth satellite of Saturn, the eighth of Jupiter, and the one of Neptune are *retrograde*, or revolve in the opposite direction. The satellites of Uranus revolve in orbits which are practically at right angles to the orbit of the planet; and Phobos, the inner satellite of Mars, whirls around its planet three times while the latter rotates once, but according to the theory, its velocity should be less than that of the surface of the planet.

6. The masses of the various planets, and the densities of the rings from which they are said to have originated, are entirely different from what we should expect from the theory.

Accordingly, Professor Hale, director of the Mount Wilson Observatory, says, "It can hardly be denied that Laplace's idea of the development of the solar system must be reconstructed or abandoned."

Within the past two or three decades, another hypothesis, called the planetesimal hypothesis, has been attracting the attention of those who persist in thinking that human ingenuity can hit on the method of origin of the solar system. This hypothesis is founded on almost precisely opposite principles from the one already considered, in that it starts with an aggregated mass of matter, and would explain the planets as having originated by a disruptive expansion, instead of by a condensive attraction. But it need not further concern us here, as no human guessing could possibly hit on the method of origin of our world and its companion planets. As easily might an infant correctly guess how a locomotive or a steamship is built.

It will be more profitable to consider some things that we really know about the earth as it now is.

Form, Size, Density, Rigidity. The earth is spherical in form, but slightly flattened at the poles, its polar diameter being about 26.8 miles less than the equatorial, which is about 7,926 miles. Its circumference is 24,899 miles. Its mean density as a whole has been computed by various methods to be about 5.6, or

twice that of the more common minerals, such as calcite (2.72) and quartz (2.65), and about two thirds that of pure iron. The average density of the outer shell of the earth is about 2.7; and thus the interior must be quite different in composition from the outer part. We really know nothing more than this regarding the character of the interior; but there are reasons for thinking that there is no distinct outer crust, but that the density increases gradually with the depth.

As a whole, the earth is calculated to be about 1.5 times as rigid as hard steel, in order to resist the deforming influences of the tidal pull of the moon and the sun. The fact that the earth retains its shape in spite of these attractive forces exerted upon it, is the best kind of proof that its interior is not in that liquid state which was long taught for a fact by all writers on geology. As a whole, the earth is also fully as elastic as steel.

The atmosphere may be considered a part of the earth, thus adding one or more hundred miles to its total diameter. From evidence given by meteorites, the atmosphere is supposed to extend in an attenuated form some 200 miles above the earth's surface. Owing to its ready compressibility, the lower layers of the atmosphere are very much denser than the upper, with the result that one half of the total mass of the air is found within the lower 4 miles above the sea level. And if the aërial ocean could be made of uniform density throughout and similar to that part now at the sea level, its total height would then be less than 5 miles.

Underground Heat. The phenomena of volcanoes, with other phenomena which will be more fully discussed in a later chapter, convince us that at least certain parts of the earth are very hot. Many observations have also been made in deep mines and borings, from which we learn that there seems to be a more or less steady increase of heat with increase of depth, at least to a certain depth. The average rate of increase has been stated at 1° F. for every 60 feet of depth; but the rate is so *unequal* in the various localities observed, and even so *irregular* for the different depths in the same locality, that the figures usually given along this line are of little significance, and probably quite misleading. Local developments of heat due to chemical processes, such as the oxidation of ores containing sulphur, are constantly encountered here and there, and very inconveniently high temperatures have been encountered in certain deep mines and in some of the tunnels through the Alps.

But the present writer has averaged the 500 odd observations recorded by Prestwich in his discussion of this subject, these ob-

servations being all the reliable temperatures taken in mines, artesian wells, etc., which this author could find recorded ("Controverted Questions," pp. 249-264); and it turns out that *the average* of all these recorded temperatures is only 69.23° F., which is *not higher than the average surface temperature must have been* when most of the fossiliferous strata were deposited, for they contain the remains of corals and palms in the

FIG. 5. Mme. Curie, the discoverer of radium.

latitude of England and Canada, and even warm temperate conditions throughout the arctic regions. Hence it would seem that we might well claim a respite from this overworked argument based on the increase of heat with increase of depth, until we have gone down a good deal deeper than any observations yet recorded.

These facts, with others that might be mentioned, have led many of our leading geologists to say that below the superficial zone the temperature seems to be practically stationary, and that

when we descend below the reach of all local superficial influences there is probably no further increase of temperature with increase of depth. As one celebrated author has expressed it, we may "consider it as more likely that the increase of temperature is at a constantly diminishing rate, so that the interior temperatures do not exceed those with which we are acquainted on the surface." (Grabau.)

Since the discovery of *radioactivity*, this property of matter has been appealed to as a probable source of underground heat. Certain elements, as thorium and uranium, are constantly disintegrating or breaking down into other elements, such as helium, radium, and lead, the process being accompanied by the liberation of relatively enormous quantities of heat. Most rocks, especially the igneous ones, contain more or less of these radioactive substances; and it is possible that radioactivity may be an important factor in the development of whatever internal heat the earth now possesses. Some geologists have even thought that this factor might be sufficient to account for volcanic action. "There is wide diversity of opinion on the subject and, at present, this view has not advanced beyond the speculative stage." (Pirsson.)

Proportion of Land and Water. The total area of the surface of the globe has been calculated to be 196,940,000 square miles. About 69.6 per cent of this, or 137,000,000 square miles, is covered by water; and about 30.4 per cent, or 59,870,000 square miles, is dry land. There is a northern or land hemisphere comprising about 41,000,000 square miles, with less than half this amount of dry land in the southern or water hemisphere. The center of this northern or land hemisphere is in the region near the western part of the British Channel.

The oceans occupy various sunken areas or depressions, varying in depth from 500 to nearly 31,000 feet, the waters in these depressions being all connected. The average depth of the ocean is about 13,000 feet, while the average height of the land is only about 2,300 feet. Hence the ocean is about 5.6 times as deep as the land is high; and as the ocean surface is about 2.8 times that of the land, *there is about 15.6 times as much water below the sea level as there is land above it.* From this it follows that, if all the present dry land should sink beneath the ocean, the water would be raised only about 650 feet, or little more than ten times the height to which the tide sometimes rises in the Bay of Fundy. Furthermore, if all the present inequalities of the globe were smoothed out, so that all the solid part would be of a uniform level, *it would be completely covered by the waters to a uniform depth of about 9,000 feet, or 1.56 miles.* "If a ball three feet in diameter were dipped into water, and withdrawn, the film of wetness adhering to it like a skin of varnish would represent the ocean." (Pirsson.)

Compared with its size, the globe is almost smooth, and its relief, as shown by the mountains and the oceanic depressions, is extremely small. If a circle representing the earth be drawn on a blackboard on the scale of an inch to a hundred miles, the circle would be 79 inches in diameter. On such a circle, the height of Mount Everest would be a slight irregularity .055 of an inch in height, while the extreme depth of the ocean would be represented by a depression .06 in. in depth. Evidently it would not require much of a disturbance of the earth to spill the water of the ocean pretty well over the land.

The Ocean Bottom. Around the edge of all the continents, the water continues comparatively shallow for some 50 or 150 miles from shore, forming what is called the *continental shelf* or *border*. At the outer edge of this shelf, the water is only about 100 fathoms, or 600 feet, deep; and the river sediments brought down from the lands, and the materials washed away from the coast by the waves and the currents, do not get out beyond this 100-fathom line. At this point, the waters deepen quite rapidly, and here the true oceanic area begins. The gravitational attraction of the lands also draws up the waters somewhat, so that the surface of the ocean is slightly distorted from a true level, this phenomenon being much more noticeable in such places as the west coast of South America, where the lands are very high close to the shore, than along a low-lying coast, as the Atlantic border of the Southern States.

Along the middle of the Atlantic, extending in a zigzag direction from north to south, is a wide ridge or plateau conforming in a general way to the trend of the American coast. Over this oceanic plateau, the water is from 6,000 to 12,000 feet deep, while on either side there are large areas from 15,000 to 20,000 feet below the surface. The greatest depth of the Atlantic and the largest area of deep water are located in the western part of this ocean. Elevated plateaus of a similar character are found in the other oceans. They seem like so many sunken continents; but whether or not these plateaus were once above the waters, we have no means of knowing.

If the ocean were removed from its basin, we would see no steep ridges like those of ordinary mountain scenery. A few mountain ranges having the present islands of the ocean for their summits would appear here and there; but the water has acted as a great leveler, and has smoothed out the entire ocean bottom, so that the changes of level are very much less abrupt than those on the surface of the lands.

As the bottom of the oceans may be regarded as somewhat dome-shaped, so the continents may be regarded as almost the reverse of this, many of them being somewhat basin-shaped, with rims composed of mountain chains, and with large interior basins, some of which have no exterior drainage. Curiously enough, the highest border of one or two of the continents faces the larger ocean, and sometimes very high points in such a bordering mountain region are only a comparatively short distance from a correspondingly deep part of the ocean, as off the coast of Japan, and the west coast of South America opposite Chile and Ecuador.

Mountains. With respect to their origin, three classes of mountains are recognized: those of *volcanic* or igneous origin, those formed by the *erosion* of the materials once surrounding them, and those formed largely *by movements* of the earth's crust.

Volcanic mountains will be considered in a later chapter. When studying erosion, we shall have opportunity to speak of the way in which enormous blocks of a portion of country elevated high above the general surface have been sculptured out and left standing, often in a very picturesque style, while the strata surrounding them have been carried away by the agencies of erosion. The Catskill Mountains, of New York, are of this character, as are also most of the peaks in the Glacier National Park, and others of the front ranges of the Rockies, with very many elsewhere. The enormous masses left standing around the margin of the Grand Cañon of the Colorado, which are sufficiently elevated above the bottom of the cañon to make high mountains, and which would be regarded as mountains if they could be removed and set down somewhere on an open plain, are also typical mountains of erosion (See Fig. 79).

But many of the loftiest mountains are composed largely of granite or similar rocks which do not show any signs of stratification, and if originally composed of stratified beds, they have been so changed or metamorphosed that all signs of stratification have been obliterated. Sometimes a few stratified beds are found among them here and there; but all such strata are usually seen to have been much disturbed at some time in the past, and so it has been easy for geologists to imagine that these mountains have been formed by the puckering up of the strata into folds by some enormous lateral pressure. That the strata have been tilted in thousands of instances, or occasionally crumpled into something resembling a real fold in a small way, is a truism needing no proof. But that such tilting or folding of the beds has in any material way contributed to the *height* of the rock masses involved, is merely a theory, and a highly questionable theory at

best. Certainly the enormous folds many miles high which have been described from the Alps and elsewhere, are mere picturesque fancies, and are usually founded on the supposed necessity of explaining how the strata happen now to be found in a relative order of superposition contrary to the theories long held with regard to the order in which the fossiliferous rocks ought to be found. And it is at least entirely possible that even the loftiest and most crystalline mountain masses may be understood as also *merely mountains of erosion,* the record having been complicated by more local disturbances than are seen in those mountains where all of the strata remaining are still in a horizontal position.

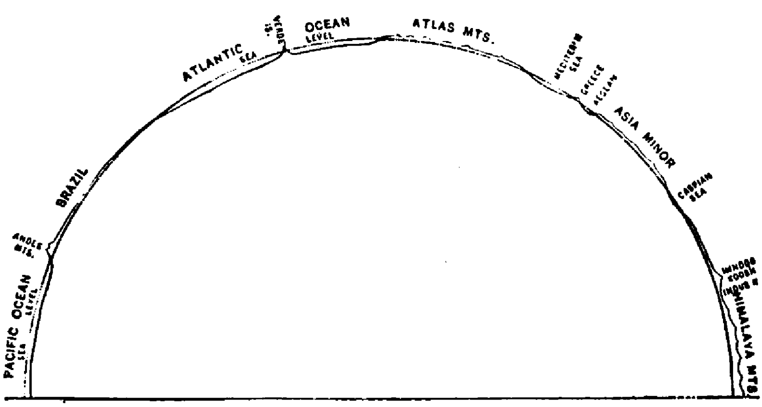


FIG. 6. The inequalities of the earth's surface exaggerated ten times.

By reference to the accompanying diagram (Fig. 6), it will be seen that the height of the mountains is in all instances quite insignificant when compared with the size of the earth. In only one or two very small areas do we find points five miles above the sea level, while not very many spots of the ocean are much more than this below sea level. With the earth's diameter approximately 8,000 miles, it is evident that even these few peaks of the mountains and the few deeps in the ocean are not more than about one sixteen-hundredth of the diameter. In other words, on a globe sixteen inches through, the greatest differences of elevation and depression from the mean or average surface would be represented as one hundredth of an inch, and this in only a very few places.

As to what it was that primarily elevated parts of what we now call the continents, or depressed other parts that we call the ocean basins, we have little or no means of knowing. At best, the real cause of such an elevation or depression of parts of the crust is a matter of speculation, not of knowledge. But granting the existence of portions elevated into what are now America, Europe, or Asia, and granting that the areas where we now find the mountain ranges were slightly *more* elevated than the rest,

the sculpturing out of the mountain peaks, and even the basin-like general form of the surface of most of these continents, would seem to follow inevitably from the general laws of denudation, as the result of the action of the waters falling upon these lands.

The sedimentary materials now found in the great basinlike interiors of the continents, like the great central valley of North America, both north and south of the 49th parallel between Canada and the United States, are probably largely the waste materials which erosion has carried away from the mountain areas on either side. Similarly the interior basins of the other continents are to be explained.

Furthermore, it will be noticed from this diagram how extremely slight the height of the great mountain ranges is, compared with the part of the earth's surface which is not thus elevated, or even as compared with the horizontal distance through the base of a great mountain range. Any mountain range is a great many times as wide as it is high; but as the whole land mass or block in this vicinity has been elevated above the surrounding areas, the rivers and streams have cleaned out valleys through this mass, thus by erosion or denudation creating the abruptness and ruggedness often so characteristic of mountainous districts. Since we know that even in quite level regions the strata deep down beneath the surface are often found to be thrown into wavelike undulations, it seems reasonable to suppose that if such areas also should be elevated and denuded, they would exhibit just such conditions as we find in the so-called folded mountain areas.

We must dismiss once for all the idea that these undulations of the strata are in any way connected with a supposed contraction of the earth's crust; for in many instances, a set of beds has been crumpled or folded while the strata both above and below are still wholly unaffected and still in a horizontal position. This disturbance of certain beds, which, as already remarked, is extremely slight as compared with the extent of the surface of the strata affected, may in some instances have been caused by the differences in the expansion and contraction of the different beds under changes of temperature, or in some instances by the settling away of part of the foundation under some enormous mass of newly deposited strata before it had time to solidify, or in other instances by the cumulative effects of earthquake waves or earth movements acting upon soft or unconsolidated strata. Such earthquake waves are known to have been very common in the past experience of the earth; and when such waves travel through sedimentary beds still unconsolidated resting upon other rocks

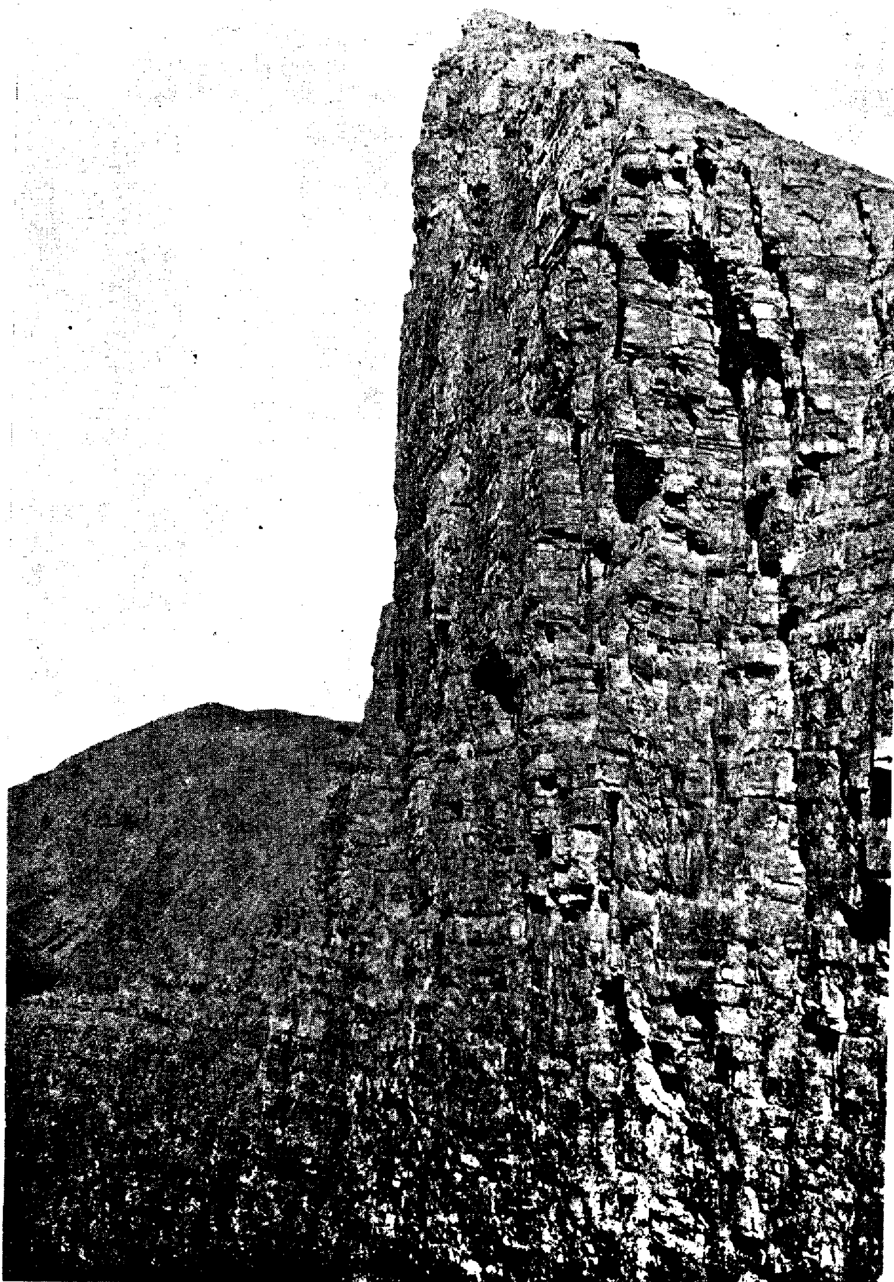


FIG. 7. Cliffs and peak of Algonkian limestone, 1½ miles northwest of Mount Cleveland, Montana, Glacier National Park. The portion of the cliff in view is about 1,200 feet high; the base below the view extends nearly vertically as far again. Goat trails extend across the face of the cliff. (Willis, U. S. G. S.)

of a different kind, such as granite, they would encounter masses of the latter with a very different modulus of elasticity rising as obstructions in their course. "The effect of this would be to heap up the strata in folds against the obstacle, somewhat as when waves break on the shore." (E. H. L. Schwartz, in a paper before the British Association at Victoria Falls, 1905; *Nature*, November 23, 1905, p. 91.)

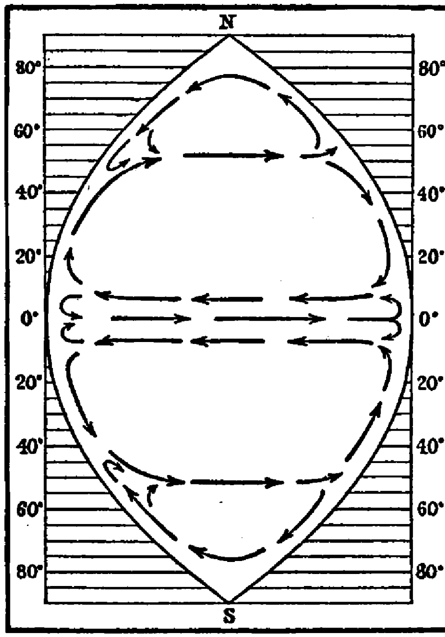


FIG. 8. Schematic representation of the direction of the ocean currents in an ideal ocean. (After Krümmel.)

Speaking in the most general way, it may be said that the earth's general surface features seem most intelligible when regarded as a modification of a former ideal arrangement of land and water, so distributed as to produce an equable climate all over the earth. Such a (hypothetical) ideal arrangement of land and water would seem to require several channels of rather deep ocean water running north and south, perhaps northeasterly and southwesterly, so as to provide for several warm tropical currents to flow into the arctic regions. The deeper parts of the Atlantic Ocean on each side of the central plateau, may represent the remnants of such ancient channels; and the central valley of North America, stretching from the Gulf of Mexico to the Arctic Ocean, may represent the filled-in ruins of another. But it should be understood that all this is only a supposition. There are many evidences on which to base such a hypothetical explanation; but they are not sufficient to raise this suggestion above the rank of a hypothesis.

Interior Basins. One of the outstanding features of the earth's surface, as we now have it, is the existence of large depressions here and there with only interior drainage. In some cases, these *interior basins*, as they are called, have small lakes in their lowest levels; and in all cases, these basins show abundant evidence that at some period in the past more or less remote they were largely or wholly filled by bodies of water. Great Salt Lake is but the dwindling remnant of a much larger lake that once occupied this region; and the existence of this ancient lake is so well attested by physical evidence on the hills around that it has received a definite name, being known to ge-

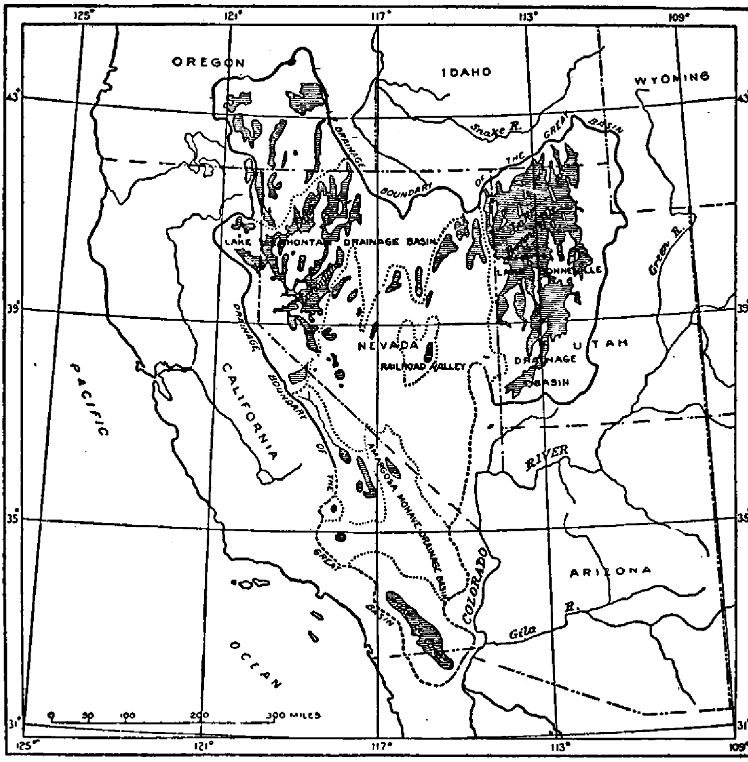


FIG. 9. Map of the Great Basin, showing the large lakes which it once contained. The various drainage basins are shown by dotted lines, the prehistoric lakes by shaded areas. (U. S. G. S.)

FIG. 10. Red Rock Pass, Southeastern Idaho, the former outlet of Lake Bonneville. Note the marshy condition of the land. (Fairbanks.)

ographers as *Lake Bonneville.* This lake once had an area two thirds as large as Lake Superior, including parts of three States. It must have been over a thousand feet deep, though Great Salt Lake is now only about forty feet deep (Fig. 9).

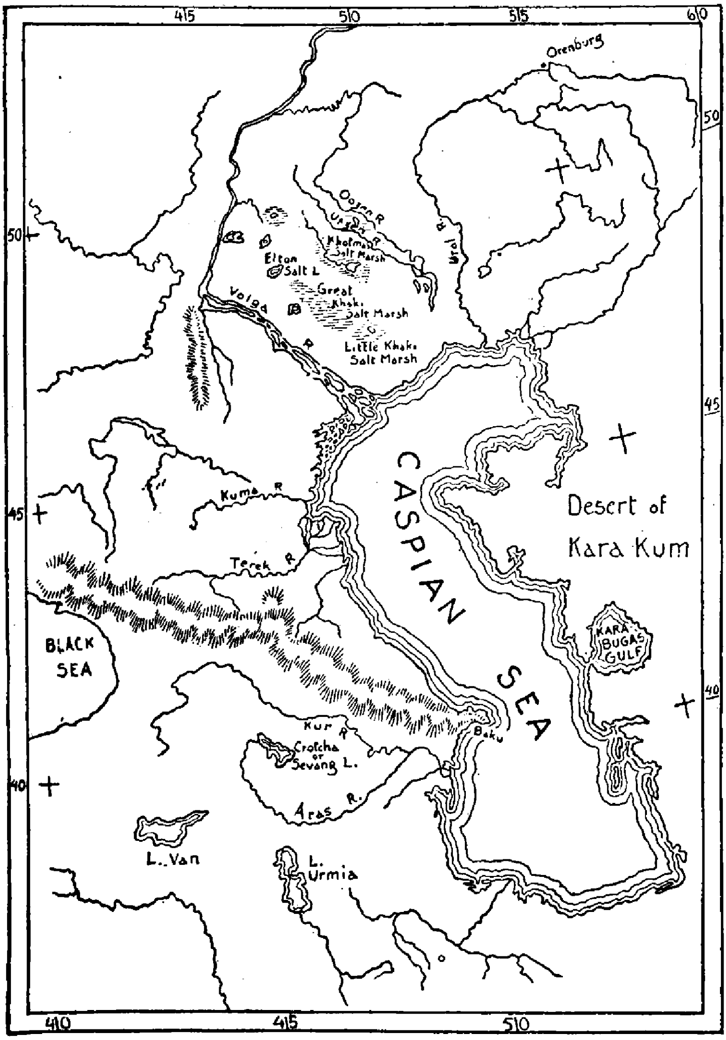


Fig. 11. Map of the Caspian Sea and vicinity. (After Grabau.)

Lake Lahontan is the name given to another body of water, which once existed to the west of Lake Bonneville; and these two great lakes occupied but a part of what is known as the Great Basin, an immense area, including practically all of Nevada, with

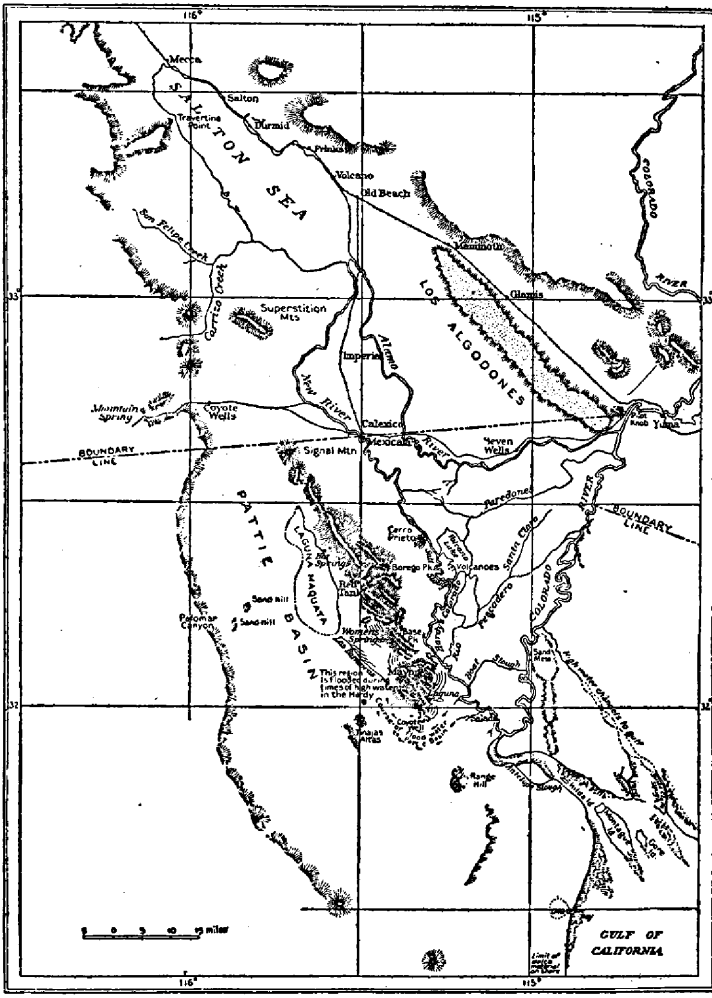


FIG. 12. Map showing mouth of the Colorado River, with the Salton Sink and Pattie Basin. (After Sykes, from McDougal, American Geographical Society Bulletin.)

portions of Utah, Idaho, Oregon, and California. Parts of this great area, such as Death Valley, are many feet below sea level; and it is quite probable that much of this area was once occupied by standing water (Fig. 9).

The *Caspian Sea* is properly a lake in an interior basin, the waters flowing into it from many sides, but the Caspian Sea itself having no outlet. It has an area about twice that of all the Great Lakes of North America. Its surface is about eighty-six feet below ocean level; and its waters are nearly fresh, because of the large volume of the Volga and other rivers flowing into it.

But in reality the Caspian Sea occupies the deepest part of a widespread depression, which includes also the Sea of Aral, and which on this account is often called the Aralo-Caspian basin. This huge interior basin is known to have been in former times more or less full of water, this enormous body of water being now called the Eurasian Mediterranean, or the Sarmatian Ocean, though its exact limits are not well known.

All over the surface of the globe are to be found similar depressions, or interior basins, with interior drainage, and with no

FIG. 13. Lake Sorkul, in the Great Pamir desert. This is a small interior basin, or without any outlet. (After Reclus.)

exterior drainage or no outlet to the ocean. Indeed, it has been estimated that about one fourth or one fifth of the entire surface of the earth is occupied by these interior basins. And, if we assume that there was once a universal Deluge (the reality of which seems to be an inevitable induction from the general facts of geology, as will appear later), it would follow that all these areas were probably at one time full of standing water, and that the water remained in these areas for many years or many centuries, gradually diminishing in extent by evaporation; but so long as it remained, this water could not fail to exert a very profound influence on the climate of the surrounding lands, and even indirectly on the rest of the globe.

Mediterraneans. Another of the general features of the globe as a whole, is the existence of more profound depressions which are now occupied by parts of the ocean, but with partial barriers between them and the main body of the ocean. The Mediterranean Sea is a typical example; and on this account, the other similar areas are called *mediterraneans*. The Gulf of Mexico, the Japan, China, and Sulu seas, with some others, are of this character. They are connected with the main ocean at the surface; but their connecting channels are shallow, so that the cold waters of the bottom of the ocean can not flow into them. The Mediterranean is nearly as deep as the ocean proper, but its bottom is much warmer than the depths of the ocean (Fig. 14); and the same is true more or less of the other bodies of water similarly situated. It seems reasonable to conclude that the comparatively warm waters of these protected depressions may represent what all the waters of the ocean once were like in point of temperature, when the arctic regions were enjoying a sort of perpetual summer. At present, the oceans at the two poles act as refrigerating plants, because they pour a constant supply of chilled, icy water along the bottom of the oceans, these icy waters rolling down even to the areas of the tropics. But on account of the shallow channel at the opening of the Mediterranean, at the Strait of Gibraltar, this icy water can not find access to the bottom of this basin, and so its bottom waters have remained comparatively warm, being now about 55° F.

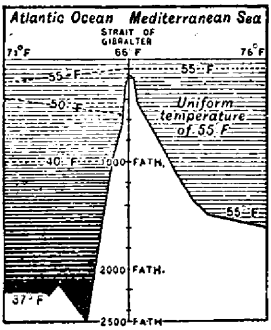


FIG. 14. The Mediterranean is nearly as deep as the Atlantic, but the Strait of Gibraltar is not deep enough to allow the cold water from the Arctic to flow into the Mediterranean. This indicates that the whole body of the ocean was once much warmer than at present.

CHAPTER II

The Organic Features of the Earth

Geologic Importance of Plants and Animals. In point of mere quantity, it may seem that the plants and animals constitute a negligible part of the earth, so far as its general features are concerned. But when we consider such a structure as the Great Barrier Reef of Australia, over a thousand miles long, built up by tiny coral polyps, or the enormous organically formed limestones which constitute a large part of the total mass of many

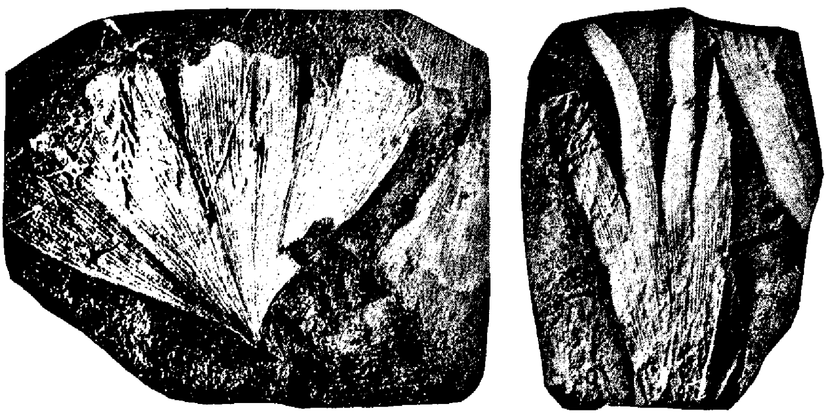


FIG. 15. Parts of palm leaves, from Cape Lisburne, Alaska. These are, of course, tropical or semitropical in habitat. (U. S. G. S.)

of the great mountain ranges of the world, or even think of the prodigious quantities of coal and oil found buried in various localities practically all over the globe and undoubtedly derived from plant or animal remains, we see that the organic part of the earth's surface is by no means insignificant.

Geology is a science of problems, the chief problem being to find out what we can about the changes through which the world passed in the long ago. And in the study of such a problem, the traces which we find of plants and animals are of the greatest assistance. Mud or sand found in one locality is very much like mud or sand found anywhere else. But shale (which is consolidated mud) containing palm leaves though found in the latitude of Northern Alaska (Fig. 15), or containing grapevines or sequoias though found in Greenland, will have a very interesting story to tell us about what these localities have experienced in the way of climatic change. Or sandstones found in New York or Wyoming

which contain the bones of elephants, will have a story to tell quite different from that of a similar sandstone beneath some city like Chicago or St. Louis which is found to contain the remains of creatures that live only in the deep waters of the ocean.

In a subsequent chapter, we shall study the special characteristics of the various kinds of plants and animals. In this chapter, we are to consider briefly the general aspects of the organic part of the world, and how the various types are now found distributed over its surface.

Environmental Factors. Plants and animals are affected by their environment, the principal factors of the environment, so far as the distribution of land forms is concerned, being *temperature* and *moisture.* Not that these factors of the environment directly produce changes in the living forms; but these living forms have the capacity to respond to the conditions in which they find themselves, and (within certain limits) have the power to adapt themselves to their environment. The changes thus induced are often very remarkable. Yet it is a fact of very far-reaching consequences, that all such changes in the individual induced by the environment *are not transmitted to the next generation;* but the members of the succeeding generation, being affected by the same environment, respond in turn, as did their ancestors, and similarly adapt themselves.

Within recent years, extensive experiments have been carried on with insects and other forms of life, whereby striking changes in such matters as the color of the wings of butterflies have been produced by subjecting the larvæ to definite changes of temperature or moisture. In this way, varieties now classed as distinct geographical races and listed under separate specific or even separate generic names, have been reproduced time and again in the laboratory. In addition to this line of experiments, we have the somewhat related results obtained by breeding and hybridization, in accord with what is known as Mendel's laws. In this way also, many new forms of both plants and animals have been produced, so different from their ancestral forms that, if found wild in a state of nature, they would undoubtedly be honored with distinct specific or even sometimes with distinct generic names by any collector. From all of which we learn to have less confidence in the sharp distinctions often made between related species when found in widely separated localities; and the alleged specific differences between the widely scattered kinds of elephants, or tapirs, or camels, or crocodiles, or pigs, or what not, lose much of their significance and fancied importance.

In the tropical regions, where heat and moisture are abundant and continuous throughout the year, both animal and vegetable life flourish in profusion. Great stretches of evergreen forests, so dense as to be utterly impenetrable by man, are to be found in almost all parts of the tropics. Not only are the trees close together, so close as to shut out the light and to render the parts

near the ground almost as dark as night, but trees and vines and hanging plants are all matted together in an inextricable labyrinth of profuse growth. Animal life also abounds. Mammals, birds, reptiles, mollusks, and insects exist in abundance and in most astonishing variety.

When we pass from such regions toward the poles, we notice that the forests become more and more open, and the undergrowth less dense; while the animal life also decreases in number and in variety. As we reach latitudes where there is a marked difference between summer and winter, the broad-leaved

FIG. 16. Trees at the timber line, on Long's Peak trail, Rocky Mountain National Park, Colorado. The trees are all inclined toward the east, or away from the prevailing winds. (Lee, U. S. G. S.)

evergreens give way to deciduous trees and shrubs, while the few remaining evergreens have only needle-shaped leaves, like the pines and the firs, or platelike leaves, as the cedars and the cypresses. The forms and habits of the animals are found also to be adapted to the change in climate; some migrate with the seasons, some hibernate during the cold weather, while others acquire a thicker covering of hair, fur, or feathers on the approach of winter, or even new coats of a very different color.

In extremely high latitudes, all trees and tall shrubs disappear, leaving only such low-growing plants as can mature their seeds during the short summer, and can lie covered by the snow during the long winter. Mosses, lichens, and strangely dwarfed and stunted shrubs, looking almost like caricatures of those found

farther south, are the only forms of plant life; while the land animals are reduced to such as can migrate back and forth with the seasons, or such as are otherwise adapted to withstand the severe winters of the arctic.

A very similar series of gradations is to be seen in ascending any lofty mountain range in the tropics. Since it becomes constantly colder the higher we ascend, the mean temperature decreasing about 1° F. for every 330 feet of elevation, the rank vegetation and abundant animal life at the foot of the mountain are soon replaced by plants and animals which strongly resemble those found on the lowlands in the cooler latitudes. Finally, also, an altitude is reached where there are no more trees, this being called the *timber line;* next the *snow line* is attained, or the point where the snow persists all the year round; and above this, all life ceases (Fig. 16).

The influence of moisture is less marked than is that of temperature, for there seems to be no part of the earth so dry as to be entirely devoid of life. Nevertheless, the changes in plants and animals are very noticeable as we pass from the dense forests of the Amazon or the Congo to the *deserts* of Sahara or of Arabia (Fig. 17). These deserts have about the same mean temperature as the tropical forests; hence their striking differences must be wholly due to the differences in moisture.

The dense tropical forests mark the regions where both moisture and heat are abundant, and continuous throughout the year. In regions which are hot but which have only a moderate rainfall, and especially where the rainfall is unequally distributed over the

FIG. 17. Mohave Desert, near Cajon Pass, California. The view shows a camp outfit and the characteristic desert vegetation. (Campbell, U. S. G. S.)

year, with plenty of rain in one season, but with a long dry season during the rest of the year, forests are absent, giving place to open meadows of grass and other grasslike vegetation. Such regions go under the various names of *llanos, pampas, prairies,* and *steppes;* and with their peculiar type of vegetation, there

FIG. 18. A tree fern, Volcano Road, Hawaii. (Mendenhall, U. S. G. S.)

is also a markedly special type of animal life in these places. In other regions, where the rainfall is still less, vegetation becomes even more scanty, resulting in what is called a *desert,* with its strikingly peculiar plants and animals.

In studying the distribution of plants and animals solely from these points of view, one is quite liable to get the impression that environment is everything, or the sole determining factor, in this distribution. But such is by no means the case; for we frequently find very dissimilar kinds of life — that is, dissimilar *floras* and *faunas* — in the same sort of climate and food supply. The equatorial parts of South America and those of Central Africa have the same sort of climate; but their floras and faunas are very

different. Australia and South Africa have very similar climates; but their floras and faunas are about as different as can be imagined. Again, many of the invertebrate animals of Florida and Georgia are much more like those of the northern parts of America and Eurasia than they are like those of the

FIG. 19. Ginkgo trees, Lafayette Park, D. C. (Lee, U. S. G. S.)

near-by Bahama Islands and Cuba, although the latter have a very similar climate. Many other such comparisons and contrasts could be made from all over the globe.

From these facts, it is evident that something else besides environment must have been concerned in the present distribution of living forms. This something else must be of the nature of *original differences in the stock* from which the present living forms have been derived. Evolutionists seek to connect these original differences with the kinds of fossils found in the same or in neighboring localities, or else imagine migrations from some distant center of distribution. On the basis of a world catastrophe, these present differences in the floras and faunas of places with similar climates must be explained as due chiefly to the original differences in the plants and ani-

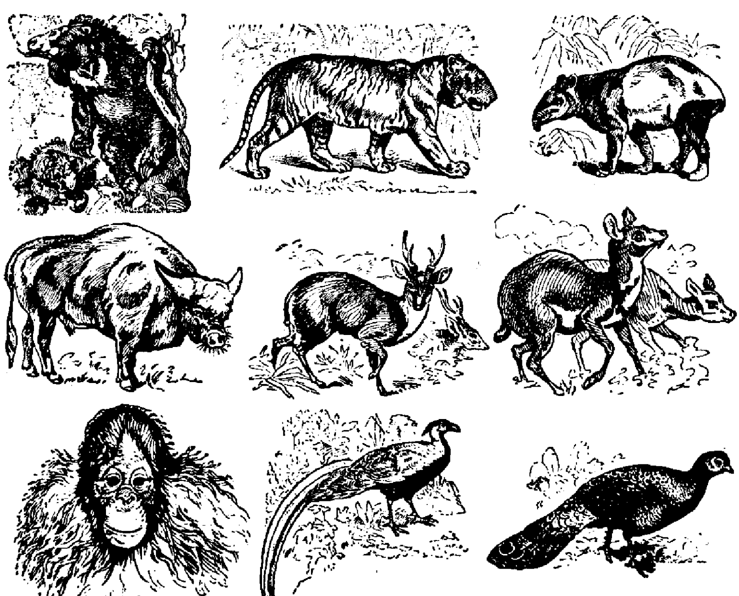
mals with which these localities were stocked after the world-desolating Deluge. From either point of view, the problem is much the same.

Habitats. However, it is a fact of prime importance, in any study of either the present or the past of our globe, that certain types of life, or certain assemblages of plants and animals, are

Duck Mole *Kangaroo* *Brush Turkey* *Emu*

FIG. 20. Characteristic animals of Australia. (After Heinman.)

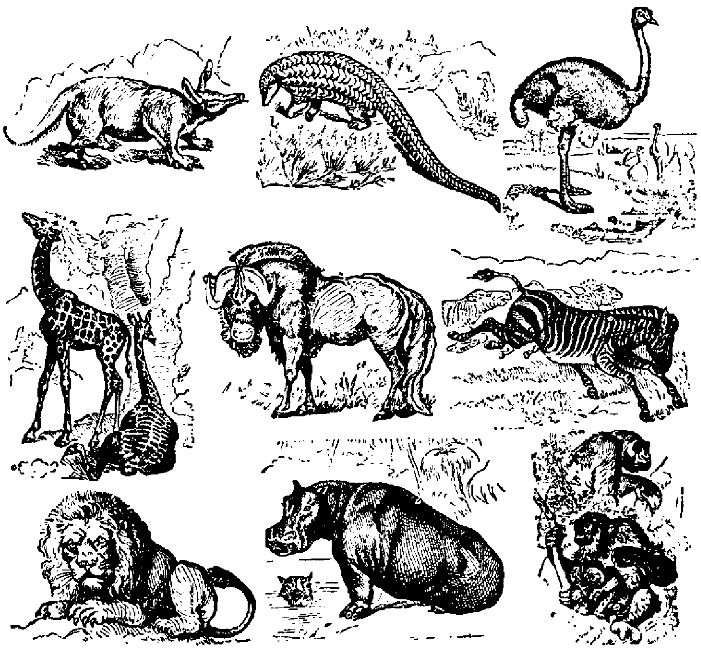
now found only in certain definite parts of the world. In other words, plants and animals *have habitats*, large or small; and species which may be related to one another by descent, or which are in some way related to other forms of life by interdependent conditions of life, are found associated or near together. From the study of the fossils found in the rocks, as will be seen in sub-



Jungle-Bear *Tiger* *Tapir*
Gayal *Muntjac* *Chevrotain*
Orang-utan *Silver Pheasant* *Peacock Pheasant*

FIG. 21. Characteristic animals of the Oriental region. (After Heinman.)

sequent chapters, we learn that in the ancient world in which these creatures lived, the habitats of the various floras and faunas were apparently even more sharply defined, more strictly confined to certain regions, than at present. And these buried groups of plants and animals, preserved in the rocks in what must often be very nearly their original habitats, are now available for



Aard-vark *Pangolin* *Ostrich*
Giraffe *Gnu* *Zebra*
Lion *Hippopotamus* *Gorilla*

FIG. 22. Characteristic animals of Africa. (After Heinman.)

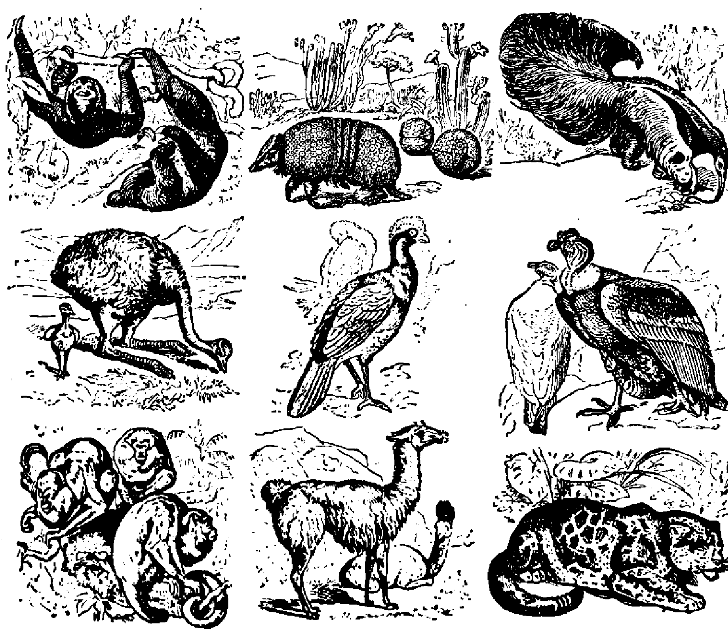
our study, and are what are called the various geological *formations*. Accordingly, the study of the present geographical distribution of plants and animals is of intense interest not merely for the present understanding of the world, but also for its bearings on the problem of what the world was like in the olden time.

Of the Pteridophyta, or higher vascular cryptogams, the ferns, the equiseta, and the lycopods are found in all latitudes from the equator to the polar regions; but giant forms, such as the tree ferns, similar to the large ferns found as fossils in the coral beds, are now confined to the warmer parts of the world, and do not flourish beyond the parallel of 35° (Fig. 18). The modern palms have about the same limit of range, though their fossils show that they formerly spread also over all the temperate regions. The conifers are found in all zones. The yews are warm temperate species;

while the cycads, found so abundantly in the Coal Measures, are now confined to the tropical or semitropical regions. The ginkgoes, or maidenhair trees, which also occur abundantly in the Mesozoic rocks, are now found as a single cultivated species in China and Japan, from which they have been imported to this country and are now widely grown for ornamental purposes (Fig. 19).

The Biological Regions. The world has been marked off into biological *regions,* six in number, which contain more or less distinct assemblages of plants and animals, though, for the purposes of our present study, the animals only will be here considered.

1. *The Australian Region.* This includes Australia, New Zealand, New Guinea, and Celebes. The fauna of Australia is very peculiar. There are absolutely no native placental mammals, save rats, mice, and a few bats, with a wild dog; and all these have probably accompanied man. But instead, it has a great variety of marsupial mammals, such as wombats, phalangers, and kangaroos, comprising an incredible number of species with a great variety of habits. There is also a still lower variety of mammals, the *monotremes,* including the water mole, or duck-



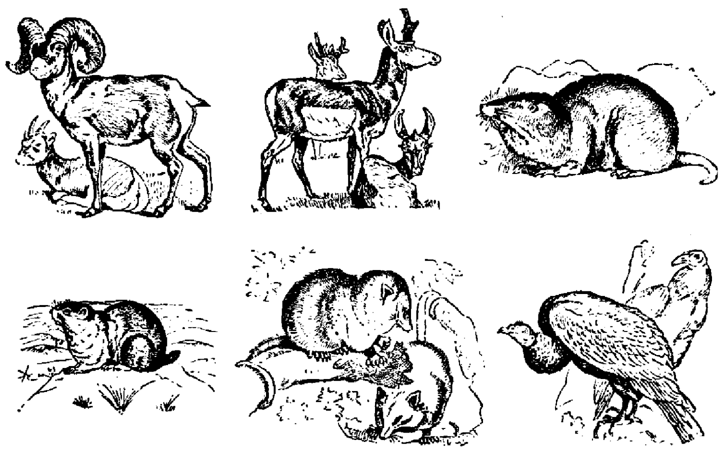
Sloth / *Rhea* / *Prehensile-tailed Monkey* — *Armadillo* / *Curassow* / *Llama* — *Anteater* / *Condor* / *Jaguar*

Fig. 23. Characteristic animals of South America. (After Heinman.)

bill, which lay eggs, though they are true mammals, and suckle their young after they are hatched.

This region has few reptiles, but numerous amphibians. Its birds are numerous; and many, such as the bird of paradise, lyre birds, parrots, and cassowaries, are in various ways remarkable.

New Zealand contains the remains of several ostrichlike birds (such as the *dinornis*), which seem to have become extinct within



Bighorn — *Prong-horned Antelope* — *Gopher*
Prairie Dog — *Opossum* — *Buzzard*

FIG. 24. Characteristic animals of North America. (After Heinman.)

modern times, though this point is uncertain. It has also a very interesting reptile, the *hatteria*, or *sphenodon*, which has been called a "living fossil," for it represents an otherwise extinct tribe, the fossil remains of which are found in the Mesozoic rocks, though not in any so-called "later" formations.

2. *The Oriental Region.* This includes India, Farther India, the Philippines, Sumatra, Java, Borneo, and the included small islands.

This region lies in the tropics; and only very narrow waters — the so-called "Wallace's line," between Borneo and Celebes — separate this region from the Australian region, which adjoins it on the south and the southeast. However, in spite of their close contiguity, these two regions are wonderfully different in their types of life.

The Oriental region has no marsupials, but it contains elephants, rhinoceroses, buffaloes, lions, tigers, and other large

members of the cat family, many deer, a species of tapir, bears, the gibbon, and the orang-utan, the two last named being restricted to this region. The birds are very abundant, as are also the reptiles and the amphibians.

3. *The Ethiopian Region.* This includes that part of Africa south of the Atlas Mountains, with Madagascar and the Mascarene Islands.

This region contains the hippopotamus, rhinoceros, elephant, giraffe, lion, hyena, zebra, gorilla and other anthropoid apes, and the lemurs; but strangely enough, no camels, or bears, or deer, or oxen, or species of Sus (pig). It contains the ostrich, which is the largest living bird in the world.

Madagascar had formerly the *epiornis* and the *dodo,* large birds somewhat like the ostrich, or the dinornis of New Zealand, but like the latter, extinct. It also contains about all the surviving lemurs (35 species), the fossils of which are found in the Eocene rocks of Europe and America, and apparently only in these regions.

4. *The South American or Neotropical Region.* Besides South America, this includes also the West Indies, Central America, and Mexico.

This region contains monkeys with prehensile tails, tapirs (the only other species of tapir being confined to the Malay Peninsula), several of the camel family, with numerous edentates, as the sloths, armadillos, and anteaters.

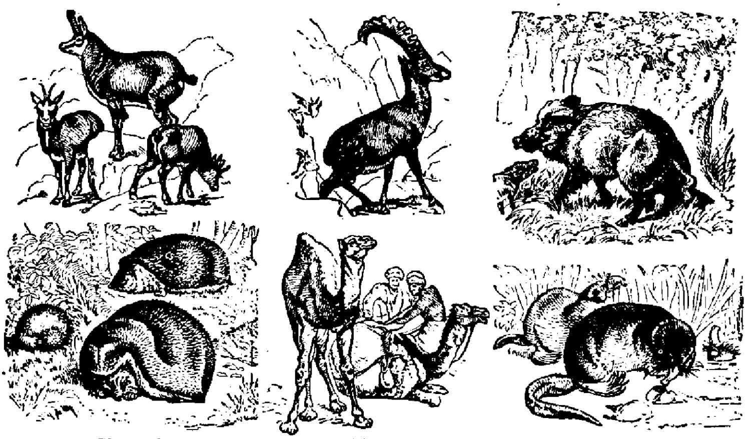
All the humming birds of the world, listed under some 400 species and 100 genera, are found in the New World, ranging from Patagonia to Alaska, with their headquarters in the Neotropical region. In this region are also numerous reptiles and amphibians; and among fishes, the very interesting *Lepidosiren,* one of the few surviving lungfishes, related to the *Dipnoi* of Africa and Australia.

This region contains a very great variety of land snails.

5. *The Nearctic Region.* This includes the United States and Canada. It surpasses all other parts of the world in its fresh-water mollusks. Among the vertebrate fishes, it has many *ganoids,* such as the gar pike and the sturgeons. Many large mammals are peculiar to this region; and the alligator, which occurs here, is represented by only one other species, which, curiously enough, is found in the Yangtze River of China. However, the cayman of South America, and also the crocodile of the Old World, may be generically related to the alligator, and all may have had a common origin.

6. *The Palæarctic or Eurasian Region.* This comprises all that part of Africa lying north of the Atlas Mountains, with all Europe, and all Asia north of India.

This is by far the largest region of all, and contains a very wide diversity of types, though when compared with its great geographical extent, it is not so prolific of animal life as are the



Chamois *Ibex* *Wild Boar*
Hedgehog *Camel* *Desman*

FIG. 25. Characteristic animals of Euro-Asia. (After Heinman.)

great tropical regions. But the study of its fauna in detail is too complicated a subject to be even sketched with profit in the very limited space which we have here.

Aquatic Species. Distribution in the ocean seems to be more a matter of vertical measurement than of horizontal. *Depth* is the chief factor, with other modifications, such as temperature, which are connected with depth.

Formerly it was taught that below 300 fathoms (1,800 feet) little or no life is to be found. But it is now known that there is no azoic or lifeless zone in the ocean; an abundant fauna, represented by many groups of animals, "extends down to the greatest depths of from four to five thousand fathoms — nearly six statute miles from the surface." (Herdman.) As the bottom of the ocean is of about the same temperature the world over, ranging from about 37° F. down to about 35° or 34°, which is the point of maximum density for sea water, there is practically ice-cold water over all the bottom of the ocean; and as all the oceans communicate with one another by deep water, *abyssal* species that are accustomed to this pressure and this temperature can migrate over the whole world.

The lower boundary of the *littoral zone,* or the belt around all the lands, extending out to the edge of the continental shelf, is about at the depth of 600 feet, or 100 fathoms. This is about the lowest limit to which light can penetrate, and hence the lowest limit at which plant life can exist. Therefore certain species of animals which exist upon this plant life, often microscopic, are necessarily limited to the waters above this depth. In turn, other species of carnivorous habits will also be limited to this region, as here only can they find their food. Large seaweeds are not found below 200 feet, as they require considerable light. The *fucoids,* or brown and olive seaweeds, which are related to the fossil seaweeds, are found on most of the shores in all latitudes.

The reef-forming *corals* are not plentiful below a depth of 150 feet, though some of them extend down as low as 240 feet; and they occur only in the warm waters of the southern seas, requiring a temperature between 68° and 78° F. Along with the corals go numerous species of fishes, mollusks, starfishes, and many other forms. Most of the mollusks, crustaceans, and many of the brachiopods inhabit these shallow waters on the continental shelf, some of them being confined to the upper beaches where the waters are less than 100 feet deep.

Absolute *darkness* probably prevails below 600 feet. The ocean currents as a rule do not extend the motion of their waters much below 1,000 feet, though in a few instances where they are confined to narrow channels, they extend to slightly greater depths. It has long been supposed that the great middle parts of the ocean, between the bottom waters and the upper 1,000 feet or so, are quite devoid of life; but recent investigations seem to indicate that life abounds throughout even these regions.

Diatoms are microscopic plants secreting silica. They are *pelagic* species; that is, they live in the open ocean, near the surface. But their minute siliceous secretions fall continually to the bottom, and cover vast areas of the South Atlantic with a soft mud or *diatom ooze.*

The *Foraminifera* are minute, almost microscopic, rhizopods, or animals related to the common amœba, but secreting calcareous shells. These also abound in the open surface waters of the ocean, and their delicate chambered shells fall like a continuous shower of snowflakes over vast areas of the ocean bottom, forming the *globigerina ooze* (Globigerina being a genus of the Foraminifera) of the North Atlantic and other oceans. They comprise numerous genera and species, some of which are identical with the fossils that make up the chalk rocks of the Cretaceous system, found in Kansas, England, and elsewhere.

The *Radiolaria* are other microscopic rhizopods, which secrete silica instead of limestone; and their skeletons, after falling to the bottom, make the *radiolarian ooze* of the Central Pacific and Indian oceans.

Both calcareous and siliceous *sponges* occur in various parts of the oceans, and their spicules or skeletons are found in all the oozes.

Until the time of the *Challenger* expedition (1872-1876), it was not known that any such deposits as these oozes are now being made at the bottom of the oceans; and so the species of animals found in the ancient chalk and other similar rocks were all said to be "extinct." We now know that in many instances, these fossil forms are identical with the kinds found in the deep-sea oozes. But though the animal remains are identical in the ancient and the modern deposits, the ancient beds are often as truly *stratified* as an ordinary sandstone or a shale, while, where the modern oozes lie, there is absolutely no movement of the waters at all, and thus a true stratified formation at the bottom of our modern oceans is impossible. Then, too, the ancient chalk beds "always contain fossils indicative of shallow water, as well as skeletons of birds, pterosaurs (flying reptiles), etc." (Pirsson.) Evidently these ancient deposits represent quite abnormal conditions of the waters, whereby the contents of the ocean depths and the forms of the shore and of the lands were mixed together.

Echinoderms, including the *starfishes,* the *sea urchins,* and the *crinoids,* are found at various depths and temperatures, some of the crinoids living in the icy waters a mile or more down. Many of these modern kinds are identical with the ancient fossil species, though the fossil kinds were formerly thought to be absolutely extinct.

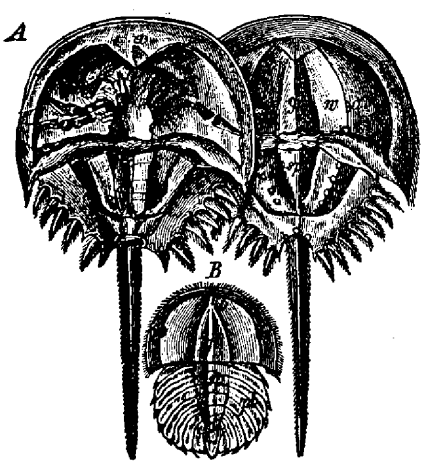


FIG. 26. Horseshoe crabs. *A, Limulus walchi.* Jurassic; Solenhofen. Ventral and dorsal views; one fourth natural size. *B, Limulus poluphemus,* the larval stage (trilobite stage) of the modern species; one half natural size. (After Steinmann.)

Some of the *mollusks,* as the oysters and the pteropods, are littoral or shallow-water species; while others, like the gastropods, are also plentiful in the deep seas. The *pearly nautilus,* an almost extinct type of cephalopod, is found only in the rather deep but warm waters between the Malay region and the Philippine and Fiji Islands.

Several kinds of *crustaceans,* as the large crabs, seem to be found almost from

pole to pole. They are chiefly littoral or shore species. The *limulus*, or king crab (Fig. 26), is found along the whole eastern coast of North America, and also in the waters of the East Indies, the two similar groups being thus widely separated. These king crabs are more or less closely related to the *trilobites* and the *eurypterids*, fossil Crustacea, which are very common in the Paleozoic rocks of all the continents.

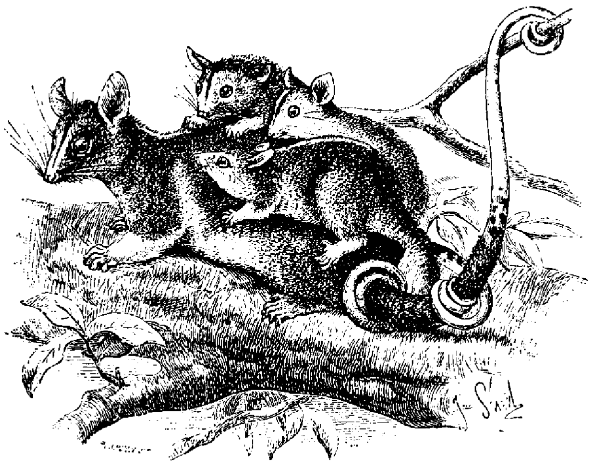


FIG. 27. The woolly opossum (*Didelphis lanigera*).

Of the vertebrate *fishes*, we can refer to only a few kinds that are especially interesting on account of their connection with some of the fossil types. The existing *ganoids*, such as the sturgeon and the pike, seem to be confined to fresh water; but this may not have been true of their fossil representatives. The *Lepidosiren* of South America, the *Polypterus* of the rivers of Central Africa, and the *Ceratodus* of Australia, with the bullhead (or cestraciont) sharks of the seas between Japan and Australia, are among the most interesting of the fishes, as they are each the sole survivors of their respective tribes — though their fossil representatives are found in great abundance in the rocks of many parts of the globe — and until quite recently they were all thought to be extinct.

Problems in Distribution. There are numerous disagreements between the present occurrence of certain living species and their occurrence as fossils in the rocks. We have already alluded to the case of the *lemurs*, the living animals being now found only in the vicinity of the island of Madagascar, while their fossils have hitherto been discovered only in Europe and North America. But this is quite an insignificant fact as compared with the occurrence of some of the larger animals. For instance, large numbers of *horses*, identical with our domestic horse *(Equus caballus)*, only larger, are found as fossils all over North America and South America from Alaska to Patagonia. But there was not a single horse in any part of the New World when the whites first came here, the wild horses with which we are acquainted in

American history having been introduced by the Spaniards. Their rapid multiplication when again placed here proves that the environment was eminently suited to their needs. How did so many uncounted thousands of them become extinct?

But the horse is not alone in this sudden disappearance. Elephants, rhinoceroses, camels, megatheriums, and glyptodonts, the three first mentioned being identical with the kinds now living in the Old World, also lived here in North America alongside these fossil horses. The huge dinosaurs may also have been contemporary. *How did such an assemblage of animals all become extinct together?* The diluvialist has an easy explanation, in saying that none of these happened to get back to this part of the world after the great disaster; but how can we account for these facts with even moderate probability on the basis of uniformity and evolutionary geology?

Again, if all the marsupials are descended from a common stock, and if we place their origin in Australia, where practically all the surviving ones are found, how shall we account for the *opossums* in North and South America (Fig. 27)? Or how did the *tapirs* become so widely scattered, some of them being in South America, and all the rest in the Malay Peninsula? Why should the *camels* be confined to the eastern parts of the Old World, and their close relatives, the llamas and the vicuñas, be found only in South America?

The *dipnoans,* or lungfishes, are confined to the streams of Central Africa, the Amazon Valley, and two small rivers in Queensland, Australia. Another kind of fishes, the *osteoglossids,* which are very interesting from the scientific point of view, are also confined to these same widely scattered localities, with the addition of the Malay Archipelago. (Günther.)

The molluscan fauna of the West Indies is almost identical with that found fossil in the Eocene rocks of the Paris basin. The collective fauna of Australia is very closely like the collective fauna of the Lower Eocene beds of North America.

Such things are remarkable, to say the least; and they could be extended and continued almost indefinitely. They show at a glance that there are many facts about the present geographical distribution of animals which are most easily accounted for on the basis of a former world catastrophe. And with the new light which we have received regarding the subject of "species," partly through experiments with changes in environment during the embryonic stage, and partly through crossing under the methods taught us by Mendel, we now know that the old specific and generic distinctions were marked off on altogether *too narrow lines.*

It is perfectly evident that both animals and plants have varied much more in a natural way than used to be thought possible; and hence two or more comparatively different forms may very well be supposed to be of a common descent. From this, it further follows that the problem of accounting for the modern diversity

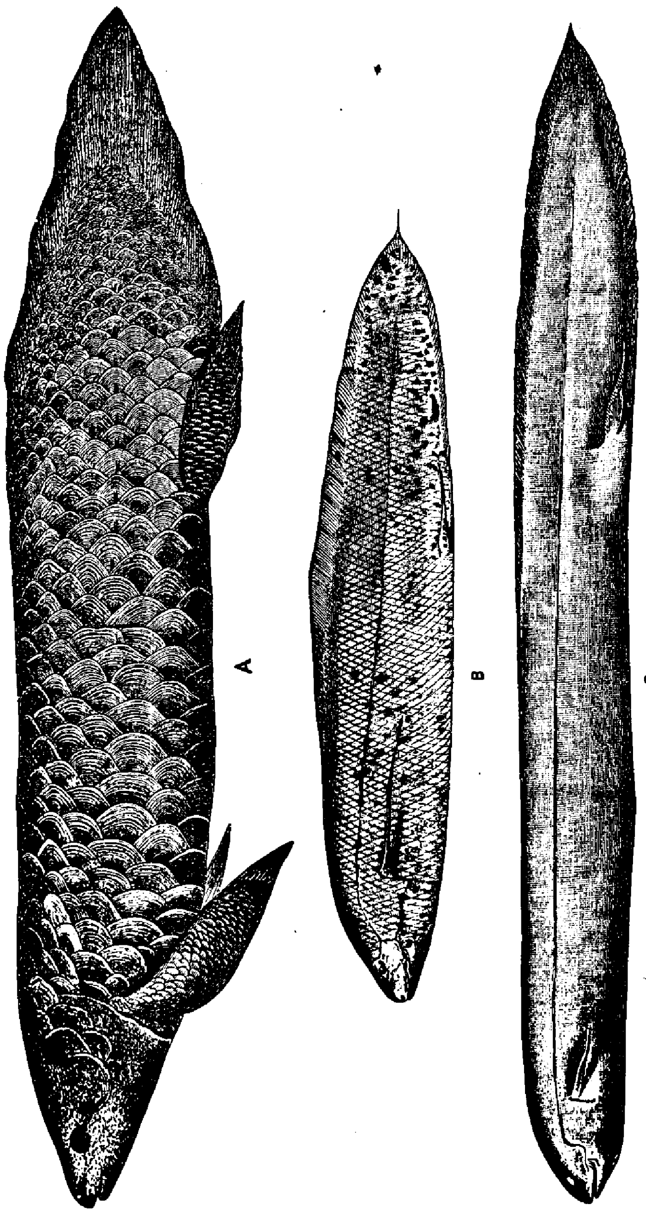


FIG. 28. MODERN LUNGFISHES

A, *Neoceratodus forsteri*, Queensland; *B*, *Protopterus annectens*, Gambia; *C*, *Lepidosiren paradoxa*, Paraguay. The lozenge-shaped markings on the surface of *B* do not represent scales, but areas of the skin outlined by pigment cells. In a fresh specimen, the scales are completely invisible, as in *C*. (*A*, from Gunther; *B* and *C*, from Lankester.)

of animals (and plants) as the survivors from a universal Deluge has been greatly simplified; for the more variation we admit as possible, the easier it is to account for the present fauna (and flora), since fewer original forms would be required to begin the present stock.

Variation. A half century ago it was supposed that plants and animals tend constantly to *vary* in all directions and to a practically unlimited extent. We now know that this is not the case. Thanks to the keen investigations stimulated by Mendel's discoveries, we now know quite definitely *how* plants and animals vary, the extent of their variations, and can even predict with accuracy the results of combinations as developed in heredity in succeeding generations.

It has been found that variations are of two kinds: first, what are termed *fluctuations,* slight differences induced by the environment or in other ways, these fluctuations being non-heritable, or not capable of being transmitted to the next generation; the other kind of variations are termed *modifications,* and are the segregates which are brought to light under Mendelian crossing. These modifications are very definitely transmitted in heredity, with all the precision of chemical law. But we also know now that these modifications *are all within the bounds of the true species;* for they are not only definitely produced by known combinations, but they can also be resolved into their originals by back-crossing. So none of these new types are really outside the bounds of the true species.

From all these considerations, we find that biology is now in the strange situation of not really knowing how new types of plants and animals, new "species" in the proper sense of the word, can arise *de novo.* Doubtless our old ideas of the limits of a "species" will have to be *enlarged* so as to include perhaps all the forms now listed under a genus, perhaps all the members of a family. Doubtless, too, many of the listed "species" will turn out to be merely Mendelian segregates which have appeared naturally in a wild state. In this respect, the views of the "lumpers" are more or less justified, for they have been inclined to group many so-called "species" together under a common name, calling these different forms only well-marked varieties. But as the net results of over half a century of study of these problems, we have a man like Bateson proclaiming that we really do not know anything at all about the "origin of species." And this is certainly true, if we mean "species" in the broadest and most correct sense of the term.

Part II — Structural Geology

CHAPTER III

Minerals and Rocks

Hitherto we have not acquired many facts with which to solve our big problems. But the records of the earth's past are all written (in so far as they are written at all) in the rocks of the crust; and all the problems of geology must be solved by reading these records. Hence we must learn to understand the language in which these records have been written. Very often in the past, this writing has been misunderstood and misinterpreted, as is seen by the many conflicting announcements which have been based on the reading of these records. Even now there is no very complete agreement as to how they should be read and interpreted.

But to learn the language in which the earth's history has been written, we must first study *the rocks,* which may be called the alphabet of this history. Then we shall need to see how these rocks are now being made and arranged in masses, and how we find those rocks which were made in the older days.

In this chapter, we shall study the subject of the rocks, their composition and kinds.

A. Elements and Simple Combinations

The number of terrestrial *elements* or uncombined substances is a little over 80. Some of these, as oxygen, nitrogen, and hydrogen, are *gases* at ordinary temperatures; but in their varied combinations, they contribute very largely to the making up of the rocks of which the earth is composed.

Oxygen is the most abundant of the elements, and constitutes 50 per cent by weight of the whole earth's structure, so far as we can tell. It is chiefly important because of its intense chemical activity, combining with practically all the other elements. Life and decay, as well as true combustion, are each dependent upon the oxygen of the atmosphere.

Combined with the various metallic elements, as potassium, sodium, calcium, iron, and aluminium, it forms essentially stable *oxides,* which are the principal constituents of the materials making up the rocks.

Carbon. All living substances, plant or animal, contain carbon. Charcoal is very nearly pure carbon, while the diamond and graphite are variant forms, or paramorphs. The best

mineral coal is about 80 to 95 per cent pure carbon. Uniting with oxygen (in the form of CO_2) in the animal body, carbon is given out by respiration and becomes the source of growth for the plant. It enters largely into the make-up of rocks, through its combination with lime, forming calcium carbonate ($CaCO_3$), the material of ordinary limestone.

Silicon. Combined with oxygen, silicon becomes silica or quartz (SiO_2), which is the most abundant and durable of common minerals. With the various oxides, it forms *silicates.* Of these oxides, alumina (Al_2O_3) is the most important, being next to silica in abundance, very hard, and almost infusible.

Sulphur. This element is a common volcanic product, and combined with the different metals, forms ores of considerable importance. In company with oxygen, it unites with various metals to form *sulphates.*

Phosphorus. With oxygen, this also forms acids, one of which combines with calcium to form calcium phosphate, the chief inorganic constituent of bones and guano. The mineral apatite, largely used for making fertilizers, is a calcium phosphate. Phosphorus unites also with iron, lead, copper, etc.

Nitrogen. Nitrogen is an essential constituent of all animal tissues, and of many plants. It comprises 79 per cent of the atmosphere, and combines with oxygen and hydrogen to make nitric acid (HNO_3), which forms *nitrates.*

B. The Chief Rock-Making Minerals

Only brief, elementary descriptions of the chief minerals can be attempted here. Certain important physical properties must first be mentioned, by means of which these minerals can often be recognized without chemical or other tests. These physical properties are *crystal form, cleavage, color, hardness,* and *streak.*

As a rule, each mineral has a characteristic form of crystal, which is usually invariable. Any natural formation of a mineral with flat surfaces and sharp edges is called a *crystal.* These crystals generally have geometric shapes; and their formation is supposed to be due to the manner in which the molecules have arranged themselves.

Cleavage is shown by minerals when they have a tendency to split or break more readily in certain directions than in others, yielding smooth, flat surfaces. Thus mica has very definite cleavage in one direction, splitting into thin elastic sheets. Some minerals, such as quartz, show no tendency to cleavage whatever.

The *color* of a mineral is usually very noticeable; but in most instances, it is not a reliable means of identification. The color of the powdered form of a mineral may be quite different from that of the portion which has not been broken up into a powder. This powdered form of a mineral is called its *streak;* and many minerals are identified by the streak when the color may be quite misleading. Hematite, or red iron ore, is red only in its streak, its ordinary color being gray or almost black. The streak of a mineral may always be obtained by scratching it with a substance which is harder than it and which will produce some powder by its scratching.

The *hardness* of minerals is a very useful means of identifying them. A scale of hardness has been worked out, ranging from certain soft substances like talc, which may be scratched readily with the finger nail, to the diamond, which is the hardest of all known substances. The following table gives a list of the scale of hardnesses:

1. Talc.	6. Orthoclase.
2. Gypsum.	7. Quartz.
3. Calcite.	8. Topaz.
4. Fluorite.	9. Sapphire.
5. Apatite.	10. Diamond.

1. Silica

Quartz. As already remarked, quartz is the most abundant mineral. It is a silicon oxide, its formula being SiO_2. Hardness, 7, not being scratched with a knife. Specific gravity, 2.65. Infusible, and insoluble in ordinary acids. When heated with soda or potash, it fuses to common glass. It has no cleavage, and in luster and transparency often resembles glass; it may, however, be dull and opaque, and of various colors, as yellow, red, brown, etc. Its crystals often make beautiful hexagonal prisms, terminated at one or both ends by hexagonal pyramids. Most of the stones and sand grains of the fields and beaches are composed of quartz. They are the remains left behind after the other accompanying minerals have been worn down or decomposed and carried away. Hence sandstones and conglomerates consist largely of quartz.

It may be distinguished by its hardness, infusibility, non-action under acids, and especially by its absence of cleavage.

Opal. This is identical with quartz in composition, though containing some water. It is uncrystallized, less hard and heavy, and dissolves more readily in heated alkaline waters.

Geyserite is the material deposited by the hot waters of geysers, and is similar to quartz in composition, as are also the siliceous secretions of sponges, the shells of radiolarians, and the minute microscopic plants called diatoms. Flint and chert are amorphous, dark-colored forms of silica, usually opaque.

2. Alumina

Sapphire, or Corundum. This is aluminum oxide, its formula being Al_2O_3.

When the crystals are blue and transparent, they are called sapphire; when red, Oriental ruby. They are the hardest of gems next to the diamond, and the coarser material, when ground, makes emery.

3. Silicates of Aluminum and Other Basic Elements

The Feldspars. These are next to quartz in abundance. Hardness, 6.5 to 7, or almost equal to that of quartz; a piece of feldspar will scratch glass. Specific gravity, 2.4 to 2.6. The color is usually white or flesh red, sometimes brownish or greenish. Feldspar is readily distinguished from quartz by its perfect cleavage in two directions, with flat, lustrous surfaces, the angle of cleavage being nearly or quite a right angle. It is more or less fusible before the blowpipe.

Orthoclase is a potash feldspar; albite, a soda feldspar; and labradorite, a lime-soda feldspar. Andesite is a species somewhat like the last named.

The Micas. These are cleavable into thin, elastic leaves, and are thus often used for the doors of stoves and lanterns. The formula varies slightly with the species; but in addition to the silica, alumina, and potash or soda of the feldspars, the micas generally contain magnesia and iron.

They may be colorless, brown, green, or black. Mica may occur as small scales disseminated through granite or other rocks; or sometimes as great plates several feet across. Muscovite or hydromica and biotite are the chief varieties.

Quartz, feldspar, and mica are the constituents of *granite,* the grains of each being readily distinguished from the others.

Other aluminum silicates, which are often disseminated through crystalline schists or slates, are: andalusite, tourmaline, garnet, and topaz.

4. Silicates of Magnesium and Iron or Calcium, with Little or No Alumina and No Water

Hornblende, or Amphibole. This is about as hard as feldspar, usually black or greenish black. Specific gravity, 2.8 to

3.2. It is brittle, and often occurs in prisms with a cleavage angle of 124° 30′. It sometimes occurs in slender green crystals or fibers; and when these fibers are long and fine like flax, it is called *asbestos.*

Pyroxene. This is similar to hornblende in composition and in most of its characteristics; but the crystals form angles of 87°, and are often eight-sided. Hence it is a paramorph of hornblende. It is a constituent of trap and many other igneous rocks.

5. Silicates of Magnesium, etc., with Water

Talc. Very soft; hardness, 1. Crystallizes in flexible leaves like mica, but they are not elastic. Usually pale green in color. Soapstone, or steatite, is a massive variety of talc, and feels soapy or greasy.

Serpentine. Soft; hardness, 3. Greenish in color. Massive or crystalline.

Chlorite. Resembles green or black mica in appearance, but is not elastic; it contains 14 per cent water, and no potash.

6. Silicates of Alumina Containing Water

Kaolinite. Pure white clay; derived from the decomposition of feldspar, water taking the place of the potash, and the substance becoming soft and amorphous. It is used in making fine pottery and porcelain.

Glauconite, or Green Earth. The material of the New Jersey marl, or greensand, of the Cretaceous and other formations. A very similar material, known as "green mud," is to be found on the modern ocean bottom in various places. The glauconite is formed inside the remains of the minute foraminifers, sea urchins, and sponges, "in a manner not yet understood." ("Encyclopædia Britannica.")

7. Carbonates

Calcite. This is the material of common limestones and marbles. Its composition is $CaCO_3$. Hardness, 3; easily scratched. Specific gravity, 2.7. Effervesces actively under hydrochloric acid, giving off CO_2. It can not be readily distinguished from other minerals by either its color or its crystals; but when heated, it turns white and amorphous, and the residue, when dampened, turns red litmus paper blue. It contains no water.

Aragonite. A paramorph of calcite, present in most uncrystalline limestones, and formed from the shells that compose these

rocks. The part of the inside of many sea shells which is called mother-of-pearl is composed of aragonite.

Dolomite. This is a calcium-magnesium carbonate, and often resembles calcite so closely that it can only be distinguished by chemical tests. It effervesces but feebly under cold hydrochloric acid, but actively when placed in the liquid and heated. Much of the limestone of the world is dolomite, or magnesian limestone, as it is sometimes called.

Siderite. An iron carbonate, $FeCO_3$. A very valuable iron ore. It crystallizes and cleaves much like dolomite, but is much heavier, its specific gravity being 3.7 to 3.9. It is white or gray in color, changing to brown on exposure, becoming limonite. Like dolomite, it effervesces in hot dilute hydrochloric acid. It is often called clay ironstone.

8. Sulphates

Gypsum. This is a hydrous calcium sulphate. It is very soft; hardness, 1; does not grate under the teeth. Color from white to black, the pure white form being called alabaster. It is often crystalline, with pearly luster. The latter form cleaves in broad plates like mica, which are nevertheless softer than those of mica, and are not elastic. When heated slightly in a test tube, it gives off its water of crystallization and becomes a powder. This powder is *plaster of Paris*. Gypsum is not affected by hydrochloric acid.

A calcium sulphate containing no water is called *anhydrite*.

Barite, or heavy spar, is barium sulphate.

9. Phosphates

Apatite. The crystals resemble beryl in being six-sided prisms, as well as in color; but apatite is much softer. It is a calcium phosphate, and is much used in making fertilizers.

10. Sulphides

Pyrite. Brasslike in color. Hardness, 7; will strike fire with steel. Its crystals are often in cubes. Formula, FeS. Often called "fool's gold." When heated, it crackles, and breaks up into small pieces, giving off sulphur. These small pieces, with much more heat, become black and magnetic, showing that they contain iron. Pyrite is, however, not good for producing iron, but is used for making sulphuric acid.

Arsenopyrite. It is silver white and brittle, but much harder than the silver ores. It contains arsenic as well as sulphur and iron.

Chalcopyrite. Copper pyrites. Gold yellow, but very unlike gold in being brittle.

Galena. Color light steel gray. Brittle. It is lead sulphide (PbS), and the most common lead ore.

Sphalerite (*Blende*). This is zinc sulphide (ZnS), and the most common ore of zinc.

11. Oxides

Hematite. A steel gray ore of iron, its streak or powder being red. In the powdered form, as red ocher, it is often used for making red paint. Formula, Fe_2O_3.

Magnetite. Called magnetic iron ore and loadstone, because attractable by the magnet and often itself magnetic. It sometimes looks like hematite, but its powder is black. Formula, Fe_3O_4.

Limonite. Color dark brown to yellow. When heated in a test tube, it gives off water, and the residue is then like hematite in composition. Continued heat makes this residue black and magnetic; that is, converts it into magnetite. The streak or powder of limonite is yellow, and a yellow earthy variety is the common paint, yellow ocher. When it does not contain sulphur as an impurity, it is a valuable iron ore, and easily worked. Like all the iron ores, it is heavy. Formula, $Fe_2O_3+1\frac{1}{2}H_2O$.

Manganite. A hydrous oxide of manganese.

Water. Water must not be omitted in any account of the constituents of rocks. Its formula is H_2O; but because of its solvent properties, it is seldom or never found pure.

C. Organically Formed Materials

Besides the materials of mineral origin already mentioned, much material for rock making has been contributed by animals and plants. When animals die, their harder parts, as bones, shells, or corals, are left behind, and vast beds of rocks have been formed in this way. Plants are the source of the coal beds.

Beds often occur which contain materials of purely organic origin mixed with sand, clay, gravel, and the like, or materials of mineral origin. Sometimes only a few organic relics remain to be distinguished. Any such organic relics preserved in a rock are called fossils, and the bed containing them is spoken of as fossiliferous.

There are but four chief organic products that contribute to the formation of rocks.

Calcareous. This is the material composing the limestones. It may be formed from the shells of mollusks, corals, crinoids, foraminifers, or rhizopods. Vast beds have no doubt been made in this way, and others are still being made; but it is a strange blunder to suppose that *all* limestones must be of organic origin, for all the lime now in the world must have existed in some form before the animals, as the latter can not be supposed to have created it. These corals, mollusks, etc., do not create their own building material, they simply work over what they find.

Siliceous. Silica is secreted by two classes of animals, the sponges and the radiolarians. The minute plants called diatoms,

FIG. 29. Phosphate mine, near the mouth of Swan Creek, Tennessee. (Hayes, U. S. G. S.)

with some algoid species of plants, also form siliceous products. The beautiful "glass sponges" are composed of silica.

Phosphatic. The bones, teeth, and shells of land animals are chiefly phosphates, as is also guano, composed principally of the excrements of birds or bats, and used extensively as fertilizer. Fossil excrements found in the rocks are called *coprolites.* The phosphatic tests of gastropods (*Cyclora*) are found in the Ordovician limestones of Tennessee; and when this limestone decomposes into a residual red clay, these phosphate tests or shells are left behind, thus forming the phosphate beds of these regions, which are now mined, and by chemical treatment, are converted into very valuable fertilizers (Fig. 29).

Carbonaceous. Plants are the main source of carbonaceous material, though animals have contributed largely toward the formation of many of the oil deposits and some of the cannel coals. However, as already remarked about the limestones, the plants must not be looked upon as having created the carbon of these deposits; they have simply worked it over.

Ordinary *wood* contains about 50 per cent carbon, with oxygen 44 per cent, and hydrogen 6 per cent. Peat is plant material partly changed toward coal, though there is abundant evidence that coal was not formed from ancient peat bogs, but from well-preserved plant material buried suddenly. Brown coal has lost still more of its hydrogen and oxygen than peat; bituminous coal, still more; and anthracite, most of all. The last named is nearly pure carbon.

Mineral *oil* and mineral *gas* contain only carbon and hydrogen. Both were probably formed by distillation from the coal beds, and other organic deposits.

D. Kinds of Rocks

Rocks may be divided into two general divisions, (1) fragmental or clastic, and (2) crystalline. But it will be convenient to insert here a few definitions as preliminary to the study of this subject.

The **fragmental rocks** are the sands, gravels, earths, and clays, usually found from the wearing away of more solid rocks, and thus called *detritus.*

Fragmental deposits are built up in successive beds or layers, and hence are called *stratified* (Latin, *stratum,* a layer). For the most part, also, they are sediments deposited by water, and are thence called *sedimentary* beds.

Crystalline Rocks. When either vapors, solutions, or fused substances change into the solid state, they generally crystallize; and noncrystalline solids may become crystalline without actual fusion, if subjected to long-continued moderate heat.

Crystalline rocks are often *igneous* or *eruptive* rocks; that is, they have crystallized from a state of fusion, having been forced up from beneath the surface, as the lavas, some granites, etc. Others have become crystalline by heat without fusion, as massive limestone becomes crystalline limestone or marble, and granitic sandstone becomes granite or gneiss. Such rocks are called *metamorphic* rocks, and they have often been produced on a large scale by the heat generated in mountain making.

DESCRIPTIONS OF ROCKS

It will be convenient to subdivide the rocks into the following three divisions:

I. Limestones, or calcareous rocks
II. Fragmental rocks not calcareous
III. Crystalline rocks

I. Calcareous Rocks

1. Limestones Not Crystalline

Massive Limestone. Compact and uncrystalline. Color whitish, gray, or nearly black. Consists essentially of calcite or calcium carbonate, but often contains clay or sand as impurities.

Many limestones are of organic origin. The dark color, when present, is usually caused by carbonaceous matter from the decomposition of plants and animals. When burned, limestone loses its carbon dioxide and becomes white; it is then quicklime or lime (CaO).

When a bed is made up chiefly of pebbles of limestone compacted together, it is called a limestone conglomerate.

Dolomite, or Magnesian Limestone. In color and texture, it resembles ordinary limestone. Many limestones are a mixture of calcite and dolomite; and sometimes the contained fossils are magnesian while the rock itself is common limestone.

Hydraulic Limestone. This is a limestone containing 20 to 30 per cent of clay, which when burned becomes a quicklime mixed with clay, which makes a very firm cement that will "set" under water.

Oölite. Ordinary or magnesian limestone consisting of small concretionary spherules, which look like petrified eggs or roe of fish, whence the name.

Chalk. This has the same composition as ordinary limestone.

Marl. A clay containing much limestone, often as shells or shell fragments. Such names as *shell limestone* or *coral limestone* explain themselves.

Travertine. A massive limestone, perhaps formed by deposition from calcareous waters. The outer walls of the Colosseum and of St. Peter's at Rome are constructed of it.

2. Crystalline Limestone

Stalagmite and Stalactite. These are deposits from water percolating through the roofs of limestone caverns, the latter name being given to the cones or iciclelike bodies that hang

from the ceiling, and the former applied to the formation on the floor under the dripping.

Marble. This is a crystalline or granular limestone. It is usually a metamorphic rock.

Dolomite. The crystalline variety of dolomite can not be distinguished from marble except by chemical tests. Unless quite pure, it is not very durable.

II. Fragmental Rocks Not Calcareous

Conglomerate. This is merely a gravel bed, composed of pebbles or rock fragments, consolidated into a firm mass. If the

FIG. 30. Contemporaneous erosion, seen in the channel of the Niagara Gorge. (U. S. G. S.) This is very evidently an example of subaqueous erosion, that is, made while the first beds were still beneath the waters.

pebbles are rounded, it is called pudding stone; if angular, breccia. These distinctions often tell us something concerning the history of the fragments composing the bed.

Grit. A hard, gritty rock, sometimes used for millstones, composed of coarse quartz sand and small pebbles, the sand grains often having sharp edges, as if they had never been washed much by moving water. It frequently accompanies the coal beds.

Sandstone. A consolidated sand bed. The descriptive names used to distinguish varieties are generally self-explaining.

Shale. This is simply consolidated mud or clay, and, like the latter, has various colors and textures.

Argillite. Called also clay slate. It is a slaty rock somewhat like shale, but, unlike the latter, it breaks into thin, even slates or slabs. Much of it is of metamorphic origin, and often it graduates into hard, thick-layered sandstones, which used to be called graywacke.

Tufa. Made up of comminuted volcanic sand or lavas more or less changed.

Clay. Soft and plastic, largely aluminous in composition, and of different colors. It usually contains particles of quartz

FIG. 31. Granite intrusions parallel to mica gneiss. Flow banding in the granite. (Keith, U. S. G. S.)

and feldspar, and traces of some iron oxide, besides the kaolin, or pure clay. On being heated, clay hardens, and the iron in it turns red, thus forming red brick. Clays that contain no iron are used to make white pottery; and those containing no feldspar can be used to make fire brick, but the potash of feldspar makes ordinary brick fusible.

Alluvium, Silt, Loess. The first two are the earthy deposits made respectively by moving fresh waters, and by the waters of bays or harbors. Loess is a singular deposit, coarse or fine, often following the course of valleys, like alluvium, but without

division into thin layers. It seems to be chiefly or wholly an ancient deposit; while alluvium and silt are modern deposits. Loess may have been deposited in a rapid, continuous manner, through deep overlying water. The adobe soil of the western United States is very similar to the loess.

Tripolite. Called also infusorial earth, and composed of the siliceous shells of diatoms. It resembles clay or chalk in texture, but will scratch glass when rubbed on it.

III. Crystalline Rocks

1. Siliceous Rocks

Quartzite. A siliceous sandstone, sometimes made to include conglomerate. Other rocks coming under this head are: siliceous slate, chert, jasper rock, buhrstone, and geyserite.

2. Rocks Having Alkali-Bearing Minerals as Chief Constituents

A. The Potash Feldspar and Mica Series

Granite. A mechanical mixture of quartz, feldspar, and mica, with no appearance of layers. Its quartz has no cleavage. There are numerous varieties, named from the color of the feldspar or other peculiarities. It is often metamorphic and eruptive in origin, but may be primitive.

Gneiss. Like granite in materials, but having the mica and other ingredients more or less in layers. There are many varieties. It is often metamorphic in origin.

Mica Schist. The mica predominates, but usually there is much quartz and some feldspar. There are many varieties, and it is usually considered metamorphic.

Hydromica Schist. Thin and schistose, made chiefly of hydrous mica, or sometimes containing also quartz.

Slate, Argillite. These rocks form a transition between the hydromica schists and the shales, and are the result of but slight metamorphism. They are finely grained rocks, that to the naked eye do not appear crystalline. As will be shown subsequently, the planes of slaty cleavage are independent of the planes of stratification, and are due to pressure.

"Perfectly gradual transitions may be traced from granite to gneiss, from gneiss to mica schist, from mica schist to hydromica schist, from hydromica schist to slate, and from slate to shale."— *Dana.*

FIG. 32. Banded gneiss, Portland Township, Ottawa County, Quebec. (Wilson, U. S. G. S.)

Felsite. This is compact orthoclase, mixed with some quartz.

Porcelanite. Baked clay. It is like flint in fracture, and gray or red in color. Formed by the baking of clay beds when they consist largely of feldspar. This often has occurred in the vicinity of a trap dike, or over large areas by the burning of coal beds underneath, as in North Dakota and Montana.

Trachyte. Consists mainly of orthoclase. It has a rough surface of fracture; differs from felsite in containing some glass, and in having a rougher surface. Ash gray or brownish in color, and eruptive in origin.

Lava. Under this name are included a number of varieties that have flowed in streams from a volcano, especially those that are scoriaceous or contain cavities. Obsidian, scoria, and pumice are some of the names in this group.

B. Potash Feldspar and Hornblende or Pyroxene Series

Syenite. This is a granitelike eruptive or metamorphic rock, having black hornblende instead of mica. When containing quartz, it is called quartz syenite. The name *syenite* comes from Syene in Egypt, where red granite graduating into quartz syenite was obtained by the Egyptians for making their obelisks and much of their architectural work.

The term **augite** is given to varieties containing pyroxene instead of hornblende.

C. Soda-Lime Feldspar Rocks

These are basic rocks, eruptive or metamorphic in origin, varying much in the kind of feldspar present, in texture, and in composition, even in the same eruptive mass. Many of the dark-colored varieties are included under the term *trap rock.* Little more than the names of the numerous varieties can be given here.

Diorite. Includes greenstone and the *red porphyry* of Egypt. Labradorite, andesite, gabbro, and dolerite, or trap, are some of the more important varieties.

3. Rocks Without Feldspar

These include garnet rock, epidosite, tourmalite, pyroxenite, hornblendite, and amphibolite.

4. Hydrous Magnesian and Aluminous Rocks

These include the chlorite and talcose schists, steatite, or soapstone, serpentine, and ophicalcite, or verd antique.

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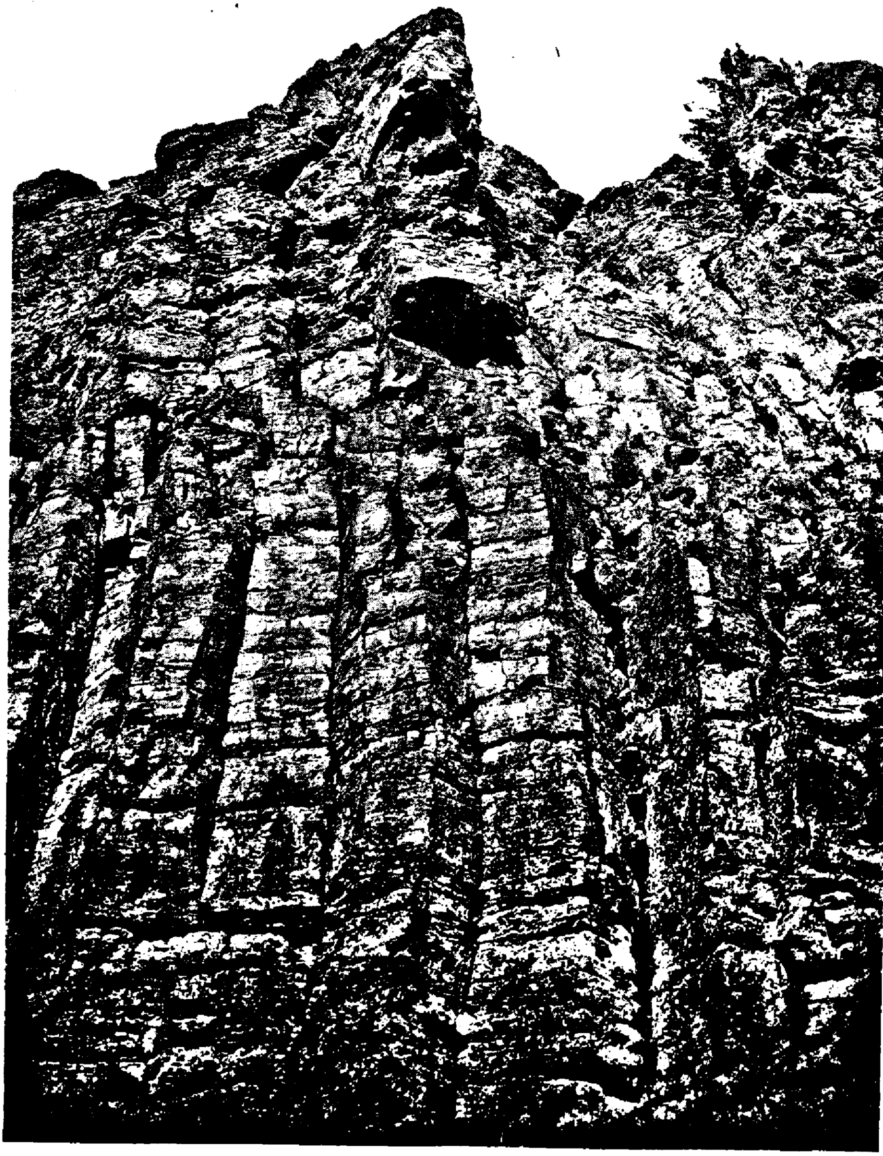

FIG. 33. Columnar structure, obsidian columns, Yellowstone National Park, Wyoming. (Iddings, U. S. G. S.)

CONSTITUENTS OF ROCKS

- I. Elements
  - Oxygen, Carbon, Silicon, Sulphur, Phosphorus,
  - Nitrogen, Chlorine, Bromine, Fluorine, Boron.
- II. Rock-Forming Minerals
  1. Silica — Quartz, Opal
  2. Alumina — Sapphire, or Corundum
  3. Silicates of Aluminum and other Basic Elements — The Feldspars, the Micas, Andalusite, Tourmaline, Garnet, Topaz
  4. Silicates of Magnesium and Iron or Calcium, with little or no Alumina and *no water* — Chrysolite, Hornblende, Pyroxene
  5. Silicates of Magnesium, etc., *with water* — Talc, Serpentine, Chlorite
  6. Silicates of Alumina containing water — Kaolinite, Glauconite, Zeolite
  7. Carbonates — Calcite, Dolomite, Siderite, Aragonite
  8. Sulphates — Gypsum, Anhydrite, Barite
  9. Phosphates — Apatite
  10. Sulphides — Pyrite, Pyrrhotite, Arsenopyrite, Galena, Chalcopyrite, Sphalerite
  11. Oxides — Hematite, Magnetite, Limonite, Manganite, Water
- III. Organically Formed Materials
  1. Calcareous
  2. Siliceous
  3. Phosphatic
  4. Carbonaceous

KINDS OF ROCKS

- **I. Limestones, or Calcareous Rocks**
  - 1. Limestones not Crystalline — Massive Limestone, Magnesian Limestone, or Dolomite, Hydraulic Limestone, Oölite, Chalk, Marl, Shell and Coral Limestone, Travertine
  - 2. Crystalline Limestone — Stalagmite and Stalactite, Granular Limestone, or Marble, Dolomite
- **II. Fragmental Rocks not Calcareous** — Conglomerate, Grit, Sandstone, Shale, Argillite, Tufa, Clay, Alluvium, Silt, Loess, Tripolite
- **III. Crystalline Rocks**
  - 1. Siliceous — Quartzite, Siliceous Slate, Chert, Jasper Rock, Buhrstone, Geyserite
  - 2. Rocks containing Alkali-bearing Minerals as Chief Constituents
    - *a.* Potash Feldspar and Mica Series — Granite, Gneiss, Mica Schist, Hydromica Schist, Felsite, Porcelanite, Trachyte, Lava
    - *b.* Potash Feldspar and Hornblende or Pyroxene Series — Syenite, Quartz Syenite, Syenite Gneiss, Augite
    - *c.* Soda-Lime Feldspar Rocks — Kersantite, Diorite, Labradorite, Andesite, Gabbro, Trap
  - 3. Rocks without Feldspar — Garnet Rock, Epidosite, Tourmalite, Pyroxenite, Hornblendite, Amphibolite
  - 4. Hydrous Magnesian and Aluminous Rocks — Chlorite Schist, Talcose Schist, Steatite (Soapstone), Serpentine, Ophicalcite (Verd Antique)

CHAPTER IV

Rock Masses

General Remarks. Having described the materials of which rocks consist, we may now pass to the study of the great rock masses which make up what we call the earth's *crust;* for we may still use this latter term concerning that part of the earth's structure which we can examine, though most people have long since discarded the old idea of a molten interior which gave rise to this expression.

Many such terms, which have arisen under false theories, are yet so expressive or have become so much a part of scientific language, that it is more convenient to continue them than to invent new ones; just as astronomy and chemistry still use many names surviving from the old superstitions of astrology and alchemy.

Many of the rock masses of our globe are *stratified* in structure, others are *unstratified,* while everywhere there are other masses which may cut across the stratified rocks in the form of *veins* or *dikes.* The last mentioned will be more properly described under the head of "Dynamical Geology," as will also the unstratified rocks proper. Hence our study here will be confined to the stratified rocks.

1. Structure and Characteristics

Stratified rocks are those which are spread out in beds or strata, the Latin word *stratum* meaning *that which has been spread out.* These beds are often of considerable extent, perhaps many square miles in area and many feet in thickness. The term *stratum* is used in geology to designate a bed or several beds that are made of approximately the same kind of rock material throughout. Thus, if limestone, sandstone, and shale lie one on top of another, each is a separate stratum, though they may individually be composed of several *beds,* and each bed may be made up of various *layers.*

Formations. On the other hand, if several independent strata are found containing a similar assemblage of life-forms or fossils, it has become the custom among geologists to class them together into what is termed a *formation;* because the old system of classifying the rocks according to their mineral or lithologic character was found to be unsatisfactory, and a new system of classification was proposed in the early part of the nineteenth century, this system being based on the kinds of fossils found in the rocks.

This latter system has now been in vogue for nearly a century; and though, through recent discoveries, we have come to discard the time-values so long associated with these different types of life, this classification of the rocks according to the fossils they contain has many things to recommend it, and should be retained.

The term *formation* thus becomes synonymous with *stratified rock mass;* and though we now know that no one type of fossil can be proved to be older than another, the term *formation* is a convenient one to use in the sense in which it has so long been employed, namely, meaning *any group of stratified rocks, large or small, whose parts are related to one another in respect to the types of fossils they contain.* Thus these parts may or may not be of the same mineral or mechanical make-up; even strata from widely separated localities may be grouped or classed together in one formation to make it complete. For example, the latter use of the term would be illustrated by the Tertiary formation, or by the Eocene formation, the latter being a subdivision of the former.

The term *formation* is often used in widely different senses by various authors. Thus it is sometimes used, though less frequently and less exactly, for a group of rocks of similar lithologic structure, as a siliceous formation, or a calcareous formation.

Positions and Conditions of Strata. The study of the order and characteristics of the strata, or beds, of a region, is termed a *stratigraphical* investigation, and this adjective is also applied to the relation that one deposit bears to another in a stratified series. It used to be taught (by the Neptunists, as Werner and his associates were called) that the earth is covered by a regular series of coats like those of an onion, which maintain the same relative position toward each other in all countries, each encircling the whole globe. But we now know that nothing much more absurd or contrary to fact could well be imagined. For a stratum which is 1,000 feet thick in one locality may in the course of a few miles become only 10 feet in thickness, or may run out altogether; or it may change from sandstone to limestone or shale; or if the first part of it contains Devonian fossils, it may change to a bed containing Silurian or Carboniferous ones.

Often a bed of coral limestone, for instance, thins out at short intervals, being in mere isolated pieces 100 feet or 1,000 feet or so in length, called *lenticular masses,* sandstone or shale occupying the space between. This condition may have been produced in any one of various ways, sometimes by parts of the original bed of limestone having been eroded or washed away by some current of the water before the succeeding beds were deposited above

it. In the larger and less exact sense of the word, all stratified beds are more or less lenticular, since they always thin out sooner or later, or are replaced by other kinds.

It is also a general rule, with some exceptions, that the beds composed of coarse materials are *small in area;* while those composed of fine materials are sometimes of enormous extent, and cover areas of many square miles. That is, conglomerates and coarse sandstones usually die out within a few miles or even less, and are replaced by other materials; while beds of shale and limestone have often been observed to cover hundreds of square miles.

The source of supply from which a mass of sand or gravel was obtained may also be traced in a general way by the principle that the beds are always thickest and coarsest near the source of supply of the material. By examination of any extensive set of beds in the light of this principle, the direction of the currents depositing the materials can usually be made out.

A *seam* is a thin layer differing in composition from the layers between which it lies. Thick seams become beds. Thus we have seams of coal, and beds of coal. A seam is said to be *intercalated,* or *interstratified,* between the layers above it and those below.

It has often been supposed that the marine basins in which certain deposits were originally formed can now be made out from a study of the materials which we find in the rocks. It has thus come about that we are often confidently informed that certain beds were deposited in a delta, or along the seashore, or in an inland lake, as the case may be; and on the accuracy of these findings, we are treated to a very confident description of the character of the ancient geography represented at the time these deposits were made. But too many uncertainties enter into such a problem; and these descriptions of paleogeography are in reality the veriest guesswork, and are in no sense worthy of being called scientific.

Other Definitions. Some of the terms used to describe beds or layers of rock need to be explained.

These layers may be (1) *massive* (that is, very thick without perceptible division into subordinate layers), (2) *laminated,* or (3) *shaly.* Laminated sandstone is used for paving in some places, and is termed *flags.*

(4) *Straticulate structure,* or *banded structure,* is a term applied to a bed made up of very thin, even layers, whether separable or not.

(5) *Slaty structure* much resembles shale, and a hardened shale is sometimes termed a *slate.* But the layers of shale are parallel to the planes of deposition, and the appearance is due to the pressure from the weight of the material above. On the other hand, slate has much more even layers, with smoother surfaces, and usually these divisions are transverse to the bedding.

This peculiar feature is termed *slaty cleavage,* and is supposed to have been produced by strong lateral pressure of some sort, or in some way not well understood (Fig. 225).

(6) *Cross-bedded structure,* or *current bedding,* is a term given to a condition where the beds are obliquely laminated,

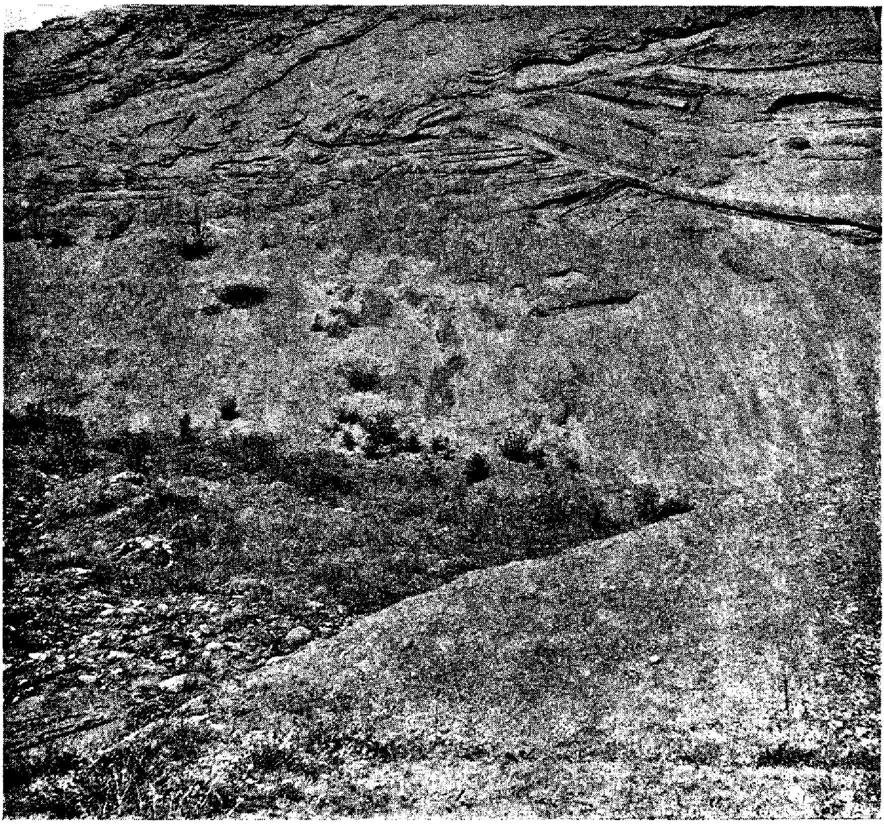

FIG. 34. Unconformities by heavy cross-bedding, in stratified sands, east of Lockport, New York. (Gilbert, U. S. G. S.)

generally alternating with horizontally bedded layers. Cross-bedding is usually observed in strata composed of coarser materials, such as conglomerates and sandstones. It is sometimes formed in modern deposits by a retreating tide rushing out from a confined estuary, or by some other strong movement of a current over a broad sandy bottom.

The term *flow and plunge structure* has been applied to an extreme type of cross-bedding; but the parts are more wavelike in appearance, and much larger, each part being sometimes 5 or 6 feet thick and many yards long. This structure is seldom if

ever produced in modern deposits. It could only be produced by very rapidly flowing waters, with an enormous supply of sand or fine gravel of uniform character as the material for composing it. The whole mass of one of these sand waves, often containing many cubic yards of material, "was produced by one fling of the waters." (Dana.)

(7) *Mud cracks* indicate that the lower bed was exposed to the sun or drying winds for some time, perhaps only for an hour

FIG. 35. Numerous concretions formed in Chico sandstone (U. Cretaceous), Coalinga district, California. Some have been broken open and show crystals inside. (Arnold, U. S. G. S.)

or more, before the next layer was spread out upon it. Mud cracks are very common in rocks of modern origin; but they are rare in the real fossiliferous rocks of the ancient world. Each reported instance needs careful consideration on its own merits.

(8) *Ripple marks* are sometimes found in the ancient rocks; but they do not necessarily indicate a sand flat, or, indeed, even very shallow water, since ripples will be formed as far down in the waters as the oscillation extends, which may be a hundred yards or more.

(9) *Raindrop* impressions or *footprints* of animals are rare, but are very interesting, and are easily interpreted.

(10) *Scratches* or *groovings,* which were evidently made by a branch or a root dragging across the soft surface of a bed before it had hardened, may be distinguished from the scratches *(striæ)* which have evidently been made on the hard, solidified rock by strong abrasion caused by movements in large masses above them, such as large rocks moved violently by currents, or a piece of rock in the foot of a moving iceberg, or other similar action. The latter marks are often falsely attributed to glaciers. A very important fact, however, to note in connection with this subject is that these latter, the striæ proper, are invariably to be found on primitive or non-fossiliferous rocks, so far as our present information extends.

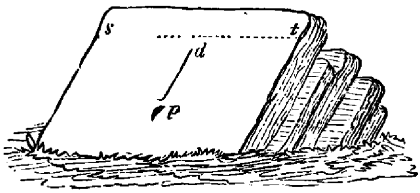

FIG. 36. Outcrop, dip, and strike. *d—p* shows the direction of the *dip,* while *s . . . t* is the *strike,* which is at right angles to the dip. The rocks here constitute an *outcrop.*

(11) *Concretions* are spheres or disks of rock, resulting from the tendency of matter to concrete or solidify around a center. The smaller kinds, found in some limestones, are called *oölites;* but others are a foot or more in diameter. When they are hollow and the cavity is lined with crystals, they are called *geodes* (Fig. 35).

2. Original Positions of Strata

We know, by common observation, that strata spread out by water are horizontal or approximately so. Perhaps no large part of the bottom of our seas or oceans is absolutely horizontal; but a grade of one foot for every 600 or 700 feet can not be detected by the eye, and we are accustomed to speak of such surfaces as horizontal. And of course the sand beds formed by our rivers, or the beds of detritus formed at the mouths of rivers or on the seashore by tidal currents, are often perceptibly sloping, because they take the slope of the bottom on which they lie. But even in these cases, the top layers are laid down parallel to the surface of the underlying beds. We shall not anticipate the question of how the ancient beds were produced, further

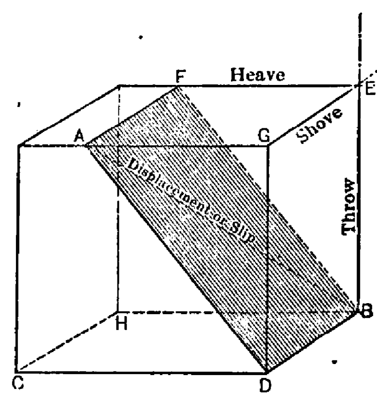

FIG. 37. Diagram to illustrate and explain the components of faulting. The fault-surface is shaded. Most normal faults are more nearly vertical than here indicated. From *A* to *F* is the strike of the outcrop. (After Pirsson.)

than to say that these same general principles must have prevailed in the past.

3. Fractured and Displaced Strata

Many of the strata of the world, however, have lost the horizontal position they originally had, and are now more or less in-

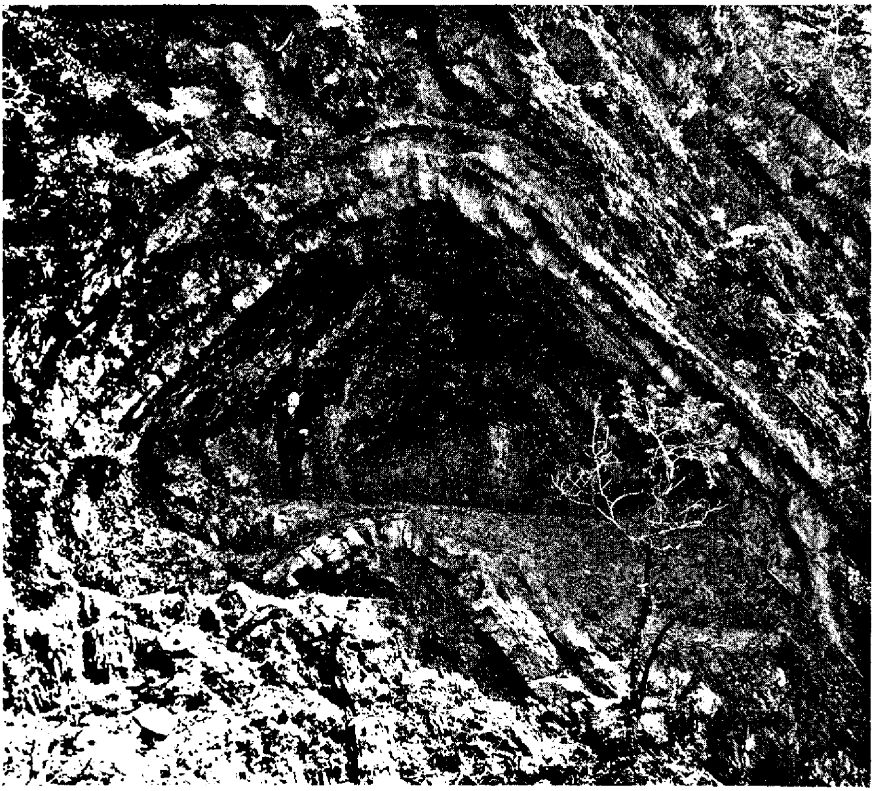

FIG. 38. Anticlinal fold in sandstones and shales, 3 miles west of Hancock, Washington County, Maryland. The rocks are Upper Silurian. (Walcott, U. S. G. S.)

clined, sometimes being even up on edge, so as to make their surfaces vertical. In some cases, they are bent like wrinkles in a piece of cloth whose edges have been pushed toward each other, these flexures being a few yards in extent, or it may be many thousands of yards (Fig. 38).

Sometimes we have examples of the superposition of bent and folded beds upon others which have not been disturbed in any way. These beds may even be found folded over upon themselves like a crushed letter *S*, so that a continuous layer of loose sand between two horizontal layers of gravel or loam might be pierced three times by one vertical boring. Such things are

difficult to explain. But the wholly undisturbed strata between which they lie show that the cause which folded them was *not* from beneath, but was superficial in its action; in other words, it could not have been due to the contraction of the earth's crust, as was formerly supposed. The instances referred to above are usually only a few yards in extent; but as there is every stage of gradation between these small, thin beds folded in this way, and the largest disturbances of mountain ranges, there is every reason to

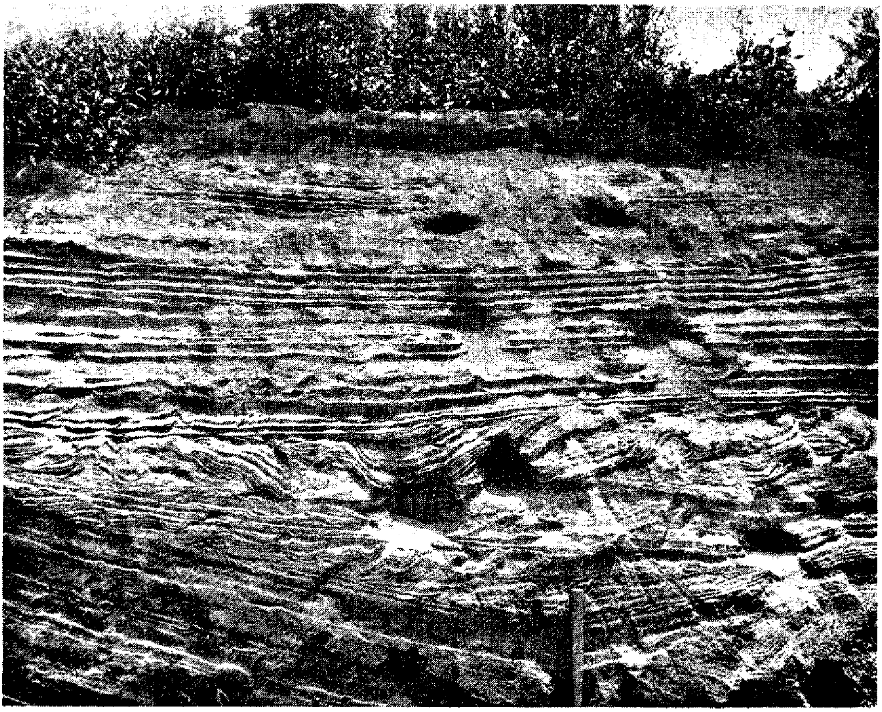

FIG. 39. Contorted laminæ in marine clay overlying drift, East Deering, Maine. Note that the middle beds are contorted or folded, while the strata both above and below are wholly unaffected. What is the explanation? (Katz, U. S. G. S.)

believe that both large and small were formed in much the same way. Of course, in this we are not admitting the reality of the so-called "overthrust folds," which are discussed elsewhere.

Sometimes the beds have been fractured, and one part has risen or fallen, so that the part of the bed on one side of a fracture is a few inches or several hundred yards above or below that on the opposite side.

Positions of Fractured and Displaced Strata. The terms used in describing the positions of fractured and displaced strata must be explained:

1. An *outcrop* is a projecting ledge of rock with the strata in sight at the surface of the ground (Fig. 36).

2. The *dip* is the angle which these beds make with the horizontal surface, and is measured in degrees; while the *direction* of this dip is also noted — as 40° to the north, or 25° to the east.

The dip is measured by an instrument called a clinometer, consisting of a square block of wood or other substance, with a plummet suspended from the upper corner, and swinging over a graduated arc on which are marked degrees and parts of degrees. It usually has a compass attached or combined with it.

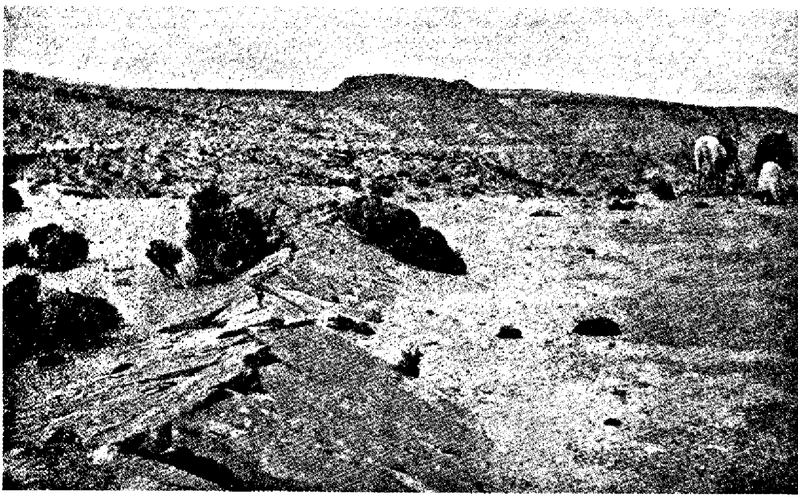

FIG. 40. Buckling in sandstone strata on account of expansion from being heated by the sun. (Smith, U. S. G. S.)

3. The *strike* is the horizontal direction at right angles to the dip. It is to be taken by the compass, and is measured in degrees, minutes, and seconds.

4. A *fault* is found where the strata have been fractured or separated, and the beds on one side pushed up or pushed down, so that there is a displacement of a few inches or many feet.

The lower side is the *downthrow*, the higher is the *upthrow*. Most fractures or faults are to be found near mountains; and all of our experience indicates that these movements are produced *suddenly*, and are accompanied by earthquakes. The real ultimate cause of this slipping of the strata is unknown.

5. *Folds* or *flexures*. These have already been referred to. A large number of the folds or flexures described in geological literature are probably based on mistakes, due to a supposed necessity of maintaining some geological theory, such as that regarding the succession of life. Each particular case reported as

a fold should be critically reëxamined, when very many of them will be found to furnish the best possible evidence refuting this succession-of-life theory.

6. Flexures are either *anticlines* or *synclines*, the upward bend in the strata, more or less like a huge arch, being the former, while the downward bend, shaped somewhat like an enormous basin, is the latter. When the strata are observed to slope only in one direction, such a structure is called a *monocline*.

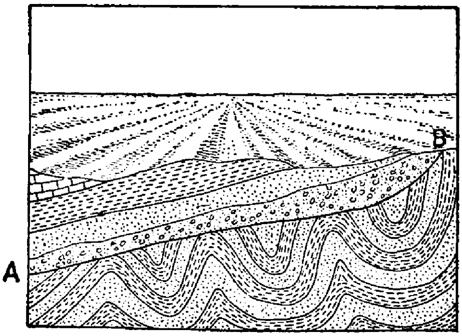

FIG. 41. Diagram to illustrate unconformity. The line A—B represents the dividing line between two sets of sedimentary rocks, the lower set having been disturbed before the upper beds were laid down. (From "The New International Encyclopædia," by permission.)

7. The terms *geosyncline* and *geanticline* were invented by Dana and applied by him to the supposed tilts in the great mass of the whole strata of a wide region, and may be illustrated by the basin of the Great Lakes, if we suppose that the strata underlying these lakes are to some degree in conformity with the bottoms of these basins.

The great continental slope of the country from the base of the Rocky Mountains toward the east might be imagined to represent a part of such a great geosyncline. In most modern cases, such as those we have mentioned above, it is doubtful if these conditions represent any real change in the original position of the strata. As used in current geology, these terms are quite fanciful in meaning, and are always coupled with unproved theories about the rise and fall of wide-extended basins of deposition, and are thus of only hypothetical value.

8. *The effects of denudation on displaced strata.* The parts of a fold that once projected above the surrounding strata may since have been washed away, because the strata in the vicinity of an anticline fold are generally so broken and fractured as to be very easily eroded. Hence, what was originally the ridge of a large anticlinal fold may since have been almost wholly washed away, and may now be represented by a deep valley which is occupied by the course of a stream.

It is commonly assumed by writers of the present day that denudation and erosion of the strata can only take place after the strata have been elevated into dry land. But there is abundance of evidence to show that enormous amounts of erosion or washing away of the strata took place beneath the waters, and while the strata were soft and freshly laid. This principle of

FIG. 41*a*. Striated limestone laid bare by wave action, at Pillar Point, on the east shore of Lake Ontario. Bluff composed of till. An irregular group of scratches crosswise of the others "are supposed to have been caused by the stranding of an iceberg." (G. K. Gilbert.) (Gilbert, U. S. G. S.)

FIG. 42. A fault cliff, or escarpment, in the House Range, Utah. Looking northward. Which side has moved relative to the other? (Gilbert, U. S. G. S.)

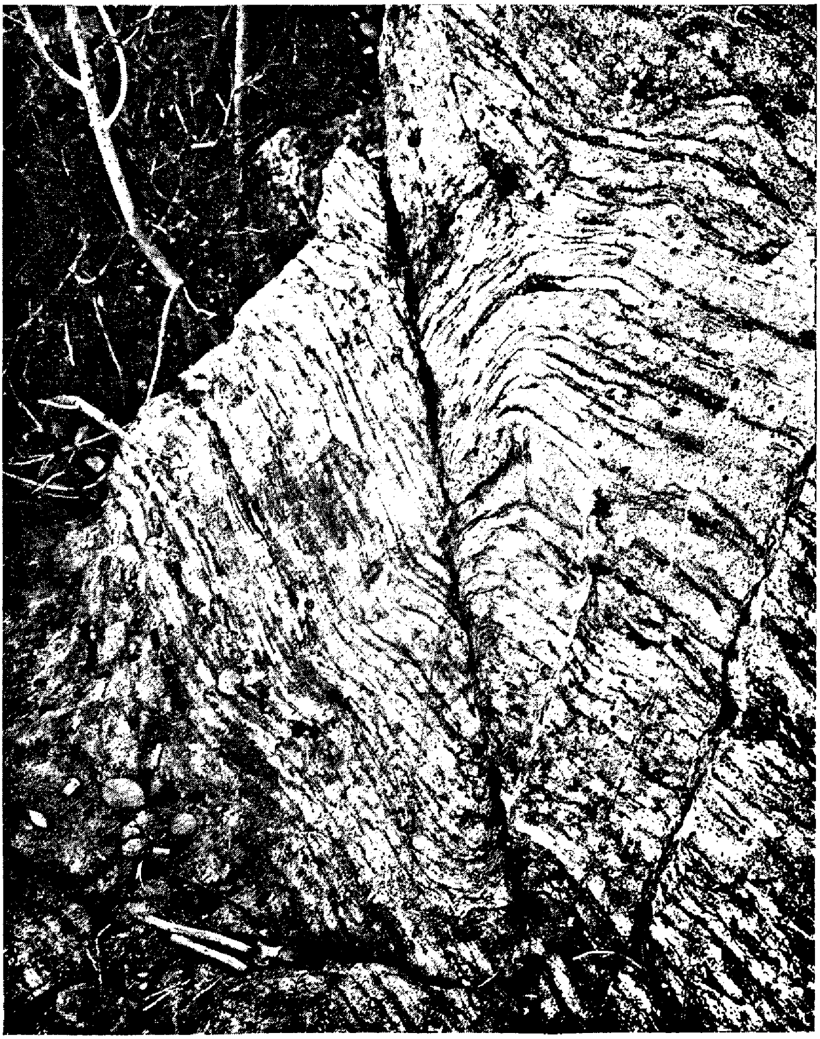

FIG. 43. A nearly vertical fault in porphyry. Which way (relatively) have these parts moved? The slight bending of these beds is termed the *drag*. (Graton, U. S. G. S.)

erosion beneath the waters, or *subaqueous erosion,* as it is termed, is a very important one in attempting to interpret the way in which former geological action must have taken place (Fig. 30).

9. *Conformity and unconformity.* When strata are found parallel to one another in bedding, as originally laid down one upon another, they are said to be conformable, or there is conformity in the bedding. But if the first bed was plainly tilted or disturbed in some way, or had a part of its surface washed away, before the next bed was laid down upon it, the two sets of strata

will not now be parallel to one another. In this case, they are said to be *unconformable* to each other, or there is an unconformity between them (Fig. 41).

By some authorities, uncomformities are divided into two classes:

(1) Where there is a distinct *difference in the dip* of the two sets of strata, the upper beds having been deposited across the upturned and truncated edges of the lower. As has been already remarked, it is usually assumed by modern writers on this subject that such a condition of affairs is proof of an immense lapse of time between the formation of these two sets of beds. That is, it is assumed that the first set of beds, after having been formed in an ordinary way, were upturned and elevated so as to form a land surface. It is further assumed that a long period of time elapsed during which the erosion of these upturned beds went on until the whole mass was more or less completely worn down to a peneplain, or down to base level. After such an amount of erosion, it is assumed, the whole set of beds was again submerged beneath the waters, and then received a new load of sediment, now represented by the upper beds which lie across the upturned edges of the lower ones.

FIG. 44. A plain eroded by the sea, showing outcropping edges of the strata at the ending of a syncline, with curving strike and inward dip. Near North Berwick, Scotland. (Geological Survey of Scotland.)

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FIG. 45. Blue banded crinoidal limestone, showing close folding and cleavage. Florence, Vermont. (Keith, U. S. G. S.)

But all of this is mere theory. The upturning and erosion of the first set of beds may have gone on beneath the waters and without these beds' ever having been lifted above the surface of the ocean. Indeed, it would be entirely possible for the first set of beds to be made, then to be tilted up and eroded by another set of currents, and afterwards the upper set of beds might have been laid down upon the eroded lower beds, and the whole thing might have taken place beneath the waters and within a comparatively brief space of time — that is, within the space of a few days at the most, if we are at liberty to suppose a violent and catastrophic action of the waters prolonged over weeks or months of time. Thus an unconformity of this character, often called an *angular unconformity*, instead of proving an immense lapse of time, may only prove a strong earthquake action followed by erosion and the deposit of other beds by a different set of currents; and all of the changes here indicated might very possibly have taken place within a few days at most (Fig. 384).

(2) Another kind of unconformity, sometimes called a *disconformity,* is that wherein the two formations are strictly parallel in their bedding, but the lower strata have been evidently eroded before the upper strata were laid upon them. This too could very easily take place beneath the waters, simply by a change in the direction of the currents.

There are many cases in the rocks where we find two sets of strata in quite evident conformity upon one another, but where there is a very great *difference between the fossils of the two sets.* In other words, the fossils of the lower set of beds may be placed in one system, while the fossils of the upper set may belong to an entirely different system; and according to the popular theory, one or more whole geological "ages" must have passed after the first set of beds was laid down and before the upper beds were deposited upon them. Yet the appearance of conformity may be

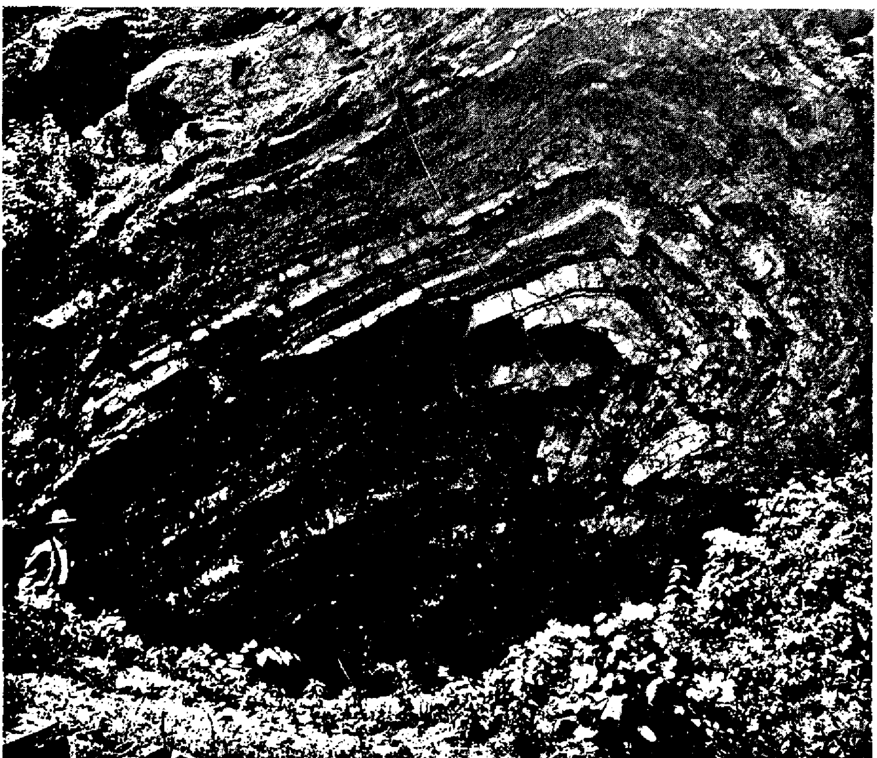

FIG. 46. An overturned anticline, Panther Gap, Virginia. The scale can be estimated by the size of the man in the lower left-hand corner. The same conditions which caused the fold — say the settling down of soft strata from lack of lateral support — might easily be continued so as to produce this overturning of the fold. (Darton, U. S. G. S.)

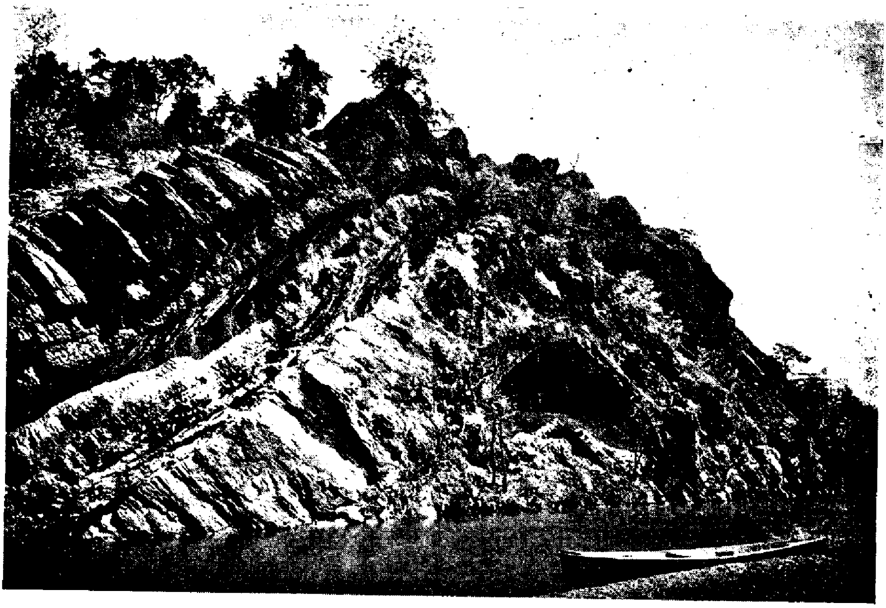

FIG. 47. Anticlinal fold in sandstones and shales, 3 miles west of Hancock, Washington County, Maryland. The rocks are Upper Silurian. (Walcott, U. S. G. S.)

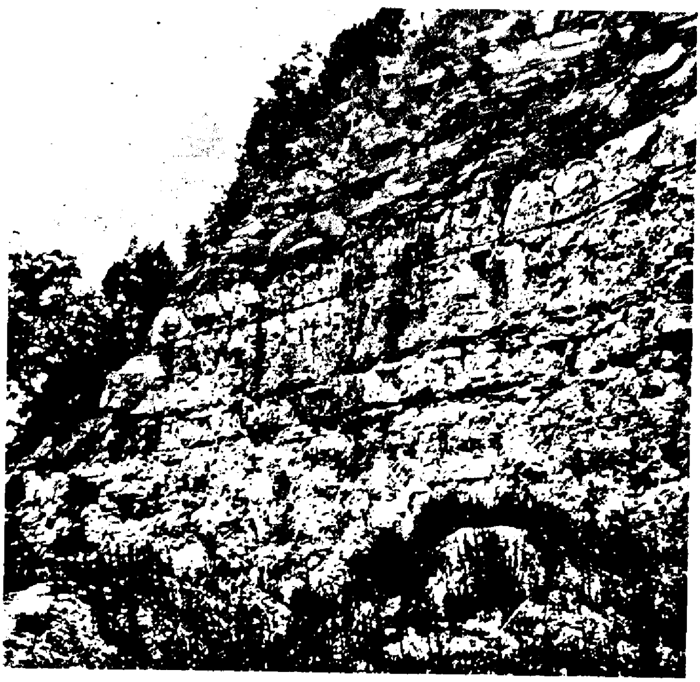

FIG. 48. Limestone cliff at Newsom, Tennessee, illustrating "deceptive conformity." At the top are black shales of the Mississippi (L. Carboniferous), resting conformably on six feet of Middle Devonian, the latter in turn resting in similar conformity upon Middle Silurian. (From Charles Schuchert.)

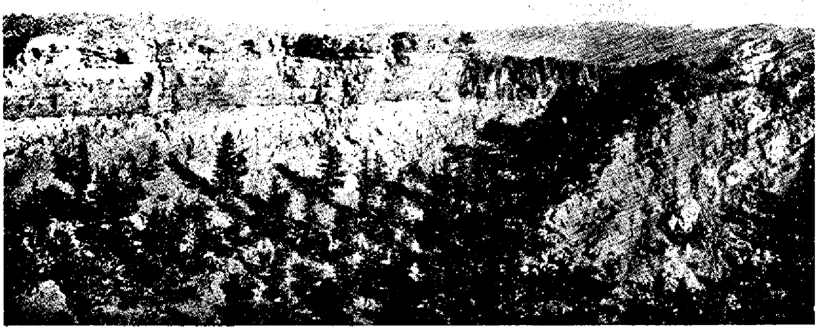

FIG. 49. An angular unconformity, near Meeteetse, Wyoming. Basal Wasatch conglomerate (Eocene) resting on the upturned edges of Laramie sandstone (Upper Cretaceous). (Fisher, U. S. G. S.)

quite perfect; and indeed, in many instances, the limestone of one may be succeeded by an exactly similar limestone in the other, or a shale may be succeeded by a shale, the two sets of strata being thus structurally and lithologically alike. Such a condition of affairs is a great puzzle to those who hold the popular theories; and they have invented a term to represent it. Such a condition is termed a *"deceptive conformity,"* or a *"non-evident disconformity."* As we shall see later, these examples of "deceptive conformity" become very strong evidence against the popular theories of the succession of life, or the geological ages. They will be considered again in the proper place.

4. Order of Arrangement of Strata

It has long been taught that the formations are to be found only in a certain definite order; and it has been thought that by reading this order aright, we can get at the true order of sequence in which the various kinds of life were introduced on the earth. It was thus supposed that geology could furnish us with something almost like a moving picture of creation in the process of its development. Of course, it was quite inevitable that such a scheme of successive ages would grow into the biological theory of evolution; for the scientific mind must naturally demand some causal connection between the successive forms of life. But we now know, as will be made plain later, that this alleged definite order of the formations is a great mistake, and that there has been no such succession of life in historical order upon the globe. This subject will be considered under the head of "Theoretical Geology."

FIG. 50. **Half Dome and Royal Arches, Yosemite Valley, California, illustrating exfoliation of the granite.**

Part III — Dynamical Geology

CHAPTER V

Chemical Work

General Remarks. It has already been stated that dynamical geology treats of two general problems:

(1) How rocks are now being made or modified;

(2) How the ancient deposits must have been produced.

The second of these problems can only be touched upon in this section; because we really need a more general knowledge of the whole subject of geology before we can solve such a problem properly.

We have already compared the work of the geologist with that of a *coroner,* and have suggested that only one acquainted with the normal action of the human body could accurately decide whether the person on whose body he was holding an inquest had died of natural causes, or from some extraordinary cause, as poison or shooting. In the same way, only one versed in the normal action of the forces of nature can form a correct estimate of the forces that anciently laid down the fossil-bearing strata. As we shall see hereafter, all the earlier investigators of geology, and even those who framed the theories under which the science is now working, were quite ignorant of many of the most important facts relating to the formation of the rocks and the burial of the fossils. And they were also profoundly ignorant of most of the living species of plants and animals whose representatives are found as fossils in the rocks. Hence it need not seem surprising if there is now an urgent need of revising some of the fundamental theories which have long prevailed regarding the forces that produced the geological work of the past.

But as a study of the fossils is of even more importance than a study of the formation of the rocks themselves, we can not frame any general conclusion concerning geological causes, until we have considered the fossils also, which we will do under the head of "Stratigraphical Geology."

Hence in this section, "Dynamical Geology," we shall treat chiefly of the present action of the forces engaged in rock making and rock modification, with merely such incidental comparisons between the ancient and the modern deposits as may be necessary to enable us to appreciate the problem in its entirety.

Weathering. The various chemical processes which act upon the rocks may be divided into two classes: those which tend to break up solid rocks into fragments, and those which tend to consolidate fragmental rocks into masses. The former work is called *disintegration;* but as chemical agencies are not alone engaged

in this work of breaking up the rocks, but are assisted by such physical processes as changes of temperature, and the action of the rains and the winds, we can not wholly ignore these processes in the present study.

All these agencies of rock disintegration and decomposition are included under the term *weathering;* and in this work of

FIG. 51. Frank, British Columbia. An enormous mass of rock, estimated at 40,000,000 cubic yards, broke away from the mountain near its top, and slid down upon the town of Frank, obliterating part of it, and burying houses, people, and coal mines forever out of sight. The rocks in the foreground are some of the fragments.

weathering, chemical and physical or mechanical changes go on side by side.

The *mechanical changes* are chiefly confined to the surface of the rocks, and are brought about by such agencies as changes of temperature, which result in the surface layers of a rock expanding or contracting more rapidly than the deeper layers. From this, large fragments may be broken off, or concentric layers may be made to scale off, especially in such rocks as granite; which results in the rounded form so characteristic of exposed granite rock masses (Fig. 50). In the northern regions, frost also has a very important influence in breaking up exposed rocks.

Chemical changes are constantly going on, both upon the surface of the earth, and deep within the earth as well. In fact, the depths of the earth constitute an immense chemical laboratory, within which all manner of chemical transformations are continually occurring. But the decomposing and disintegrating

chemical changes are confined principally to the superficial parts of the earth, down to the plane of the average level of the ground water, this superficial layer of the earth being called the *belt of weathering.*

Oxygen. Singularly enough, most of the chemical changes which take place in the rocks are performed by that omnipresent and well-nigh illimitable agent, the atmospheric gas, *oxygen.* Not indeed always, perhaps not even generally, as a gas and as a part of the atmosphere, but as present in solution in the rain and in every drop of water that touches any particle of rock, does this ceaselessly acting element do its work. Of course, this dissolved oxygen is not the only agent of chemical change. *Carbon dioxide* is an important factor; as is also *water* itself, in uniting chemically with various rocks, thus producing *hydration,* as it is termed. The reverse of oxidation is *reduction,* which means the process of extracting oxygen from a substance. Similarly the process of extracting water which is chemically united with a rock is called *dehydration.* In addition to these processes, there are two others: the making of *kaolin,* or clay; and the making of *laterite,* a kind of soil found in the tropics.

All of these processes are embraced under the study of the chemical changes taking place in the earth. Some of these changes are very complex processes, and can be studied here in

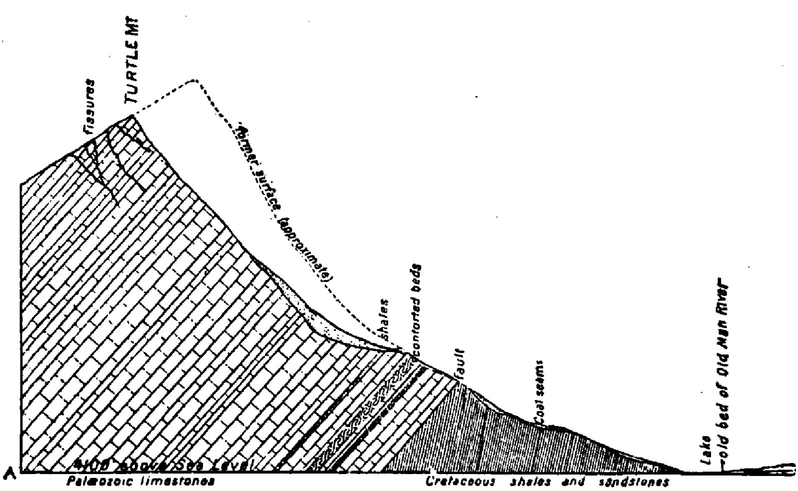

FIG. 52. Profile of Mount Turtle, Frank, British Columbia, Canada, showing the amount of material which slid away from the top of the mountain in 1903. This amount is estimated at 40,000,000 cubic yards. In this diagram, the dip of the strata, particularly of the coal beds, is greatly exaggerated, as is usual in such diagrams. And, of course, the "fault" merely marks the contact line between the overlying Paleozoic limestones and the underlying Cretaceous. (After Brock; and W. B. Scott, "Introduction to Geology," permission of Macmillan Co.)

outline only. But as the work of oxygen is the most common and the most important, it will be considered first.

About 21 per cent by volume of the atmosphere is oxygen. It forms about three fourths by weight of the animal world, four fifths of the vegetable, and half of the mineral; and taking the world as a whole, the weight of the oxygen exceeds that of all the other elements together.

Iron Compounds. Almost all the rocks contain *iron* in some form; this iron in one of its combined forms giving a red color to the rocks, in another giving a yellow color, and in still other instances giving many brilliant hues. In fact, the coloring of the rocks is mostly due to the presence in them of various iron compounds; and the changes which these iron compounds undergo are the cause of many mechanical changes in the structure of the rocks themselves.

Ferrous oxide (FeO), or protoxide of iron, is the form in which it is present in many rocks. But in this form, it is ready to take on more oxygen; and in so doing, it passes into ferric oxide (Fe_2O_3), with a considerable increase of volume. Such minerals as pyroxene, hornblende, or black mica, which contain iron in the form first mentioned, often disintegrate and break up by taking on more oxygen. Hence rocks like trap, which contain these minerals, are quite easy to decompose; for when one of the substances composing them decays, the other substances must break up into small fragments. This red oxide of iron, which we have already studied as *hematite,* which is thus formed by the disintegration of the rocks already mentioned, may go on to absorb water and thus turn into the brownish or yellowish ocher, which is the mineral called *limonite,* with a further increase of volume of 64 per cent. Limonite and hematite are often associated together; and these red and yellow colors are frequently found in the joints and cracks of rocks that are partly breaking up.

Iron is very often combined with *sulphur* in various proportions, one of the more common forms being ordinary *iron sulphide,* like pyrite or marcasite (FeS_2), which readily take on oxygen and change over into the state of yellow ocher, or limonite. The sulphur which is thus set free also takes on oxygen, and forms sulphuric acid, which in turn unites with such substances as lime, potash, soda, alumina, or magnesia, thus making sulphates.

Iron sulphide, in the form of pyrite or marcasite, often as small particles, is found in almost all the rocks of the world. And all rocks which contain these substances, or contain iron sul-

phide in any form, are readily decomposed. This iron sulphide "is the most universal of rock destroyers." (Dana.) Stones which contain iron sulphide in any form are worthless for building purposes. Even granite or sandstone that contains this mineral in even minute quantities, readily decays by oxidation, and thus the other particles of the rock are released, and the solid rock becomes merely a mass of broken particles of quartz, mica, and feldspar. This feldspar itself soon decays, and changes over

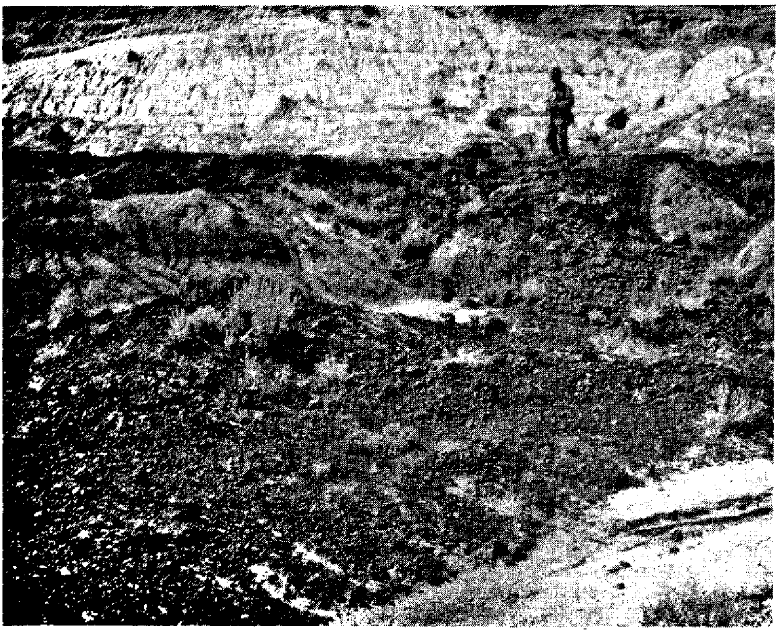

FIG. 53. Foot of bad land bluff, North Dakota. Bed of limonite (bog iron ore), in which were found numerous cones of *Sequoia*. Tertiary. (Lloyd, U. S. G. S.)

into *kaolin,* which is ordinary clay; and thus we have only sand and clay mingled together. This formation of clay is accompanied by an increase of 54.44 per cent in volume.

Whenever *siderite* (iron carbonate) is exposed to the elements, it soon changes color by the oxidation of its iron, the surface becoming brown or yellowish, because the iron has changed to limonite. Pure crystalline limestone, when it contains nothing but calcite ($CaCO_3$), or even when it is pure dolomite ($CaMgC_2O_6$), will long resist the elements of disintegration, as is seen in Milan cathedral and other Old World structures which have survived for many hundreds of years. But even one per cent of iron in a limestone of this character will soon cover the

surface with red or yellow rusty streaks, and it does not take long for such a rock to go to pieces. If manganese instead of iron is found in the limestone, the stains are black instead of red; but the limestone goes to pieces just the same.

Carbon Dioxide. Another very common agent of chemical change is *carbon dioxide.* We have learned that this gas is present in the atmosphere in the proportion of about 3.5 parts in every 10,000. Being very soluble, it is found in all rain water, and is also present in soil water because of the decomposition of animal or vegetable particles in the soil. The sea also contains some carbon dioxide in solution, since the sea is made up of the water that has flowed into it from the lands. Thus we may say that practically all of the waters on the globe contain carbon dioxide in solution, but more carbon dioxide is obtained from decaying organic matter than from the air.

But any waters containing carbon dioxide are also more capable of dissolving other rocks than pure water would be. The rocks which it especially attacks are those containing lime, magnesia, soda, or potash, or iron in the ferrous oxide state. In other words, any of these *alkali materials* are liable to be carried off by water containing carbon dioxide in solution. *Feldspar,* which is one of the constituents of granite, and which occurs in very many of the crystalline rocks, is thus caused to disintegrate by losing its lime, soda, or potash; and the substance which is left behind is what is known as *kaolin,* or pure white clay. *Granite,* when exposed to the weather, is thus eaten into and decomposed by the turning of its feldspar into clay, this decomposition extending into the granite as much as 50 or 100 feet in warm temperate climates like those of the Southern States or of South America.

All the rocks which are exposed to our examination are always divided into blocks large or small by systems of cracks or breaks, which are known as *joints* (Fig. 54). These joints become the means by which water containing oxygen in solution, or carbon dioxide in solution, may get at the internal structure of these rocks; and thus the action of decomposition may penetrate deeply into a rock, far more deeply than would be evident from a superficial examination. Even rocks which seem to be compact are nevertheless more or less filled with minute pores. Indeed, it is a common test for a building stone, to weigh a cubic inch of it, for instance, then soak the piece in water for a day or so, and weigh it again. The amount of water which it has absorbed will be the measure of the porosity of the rock, and thus

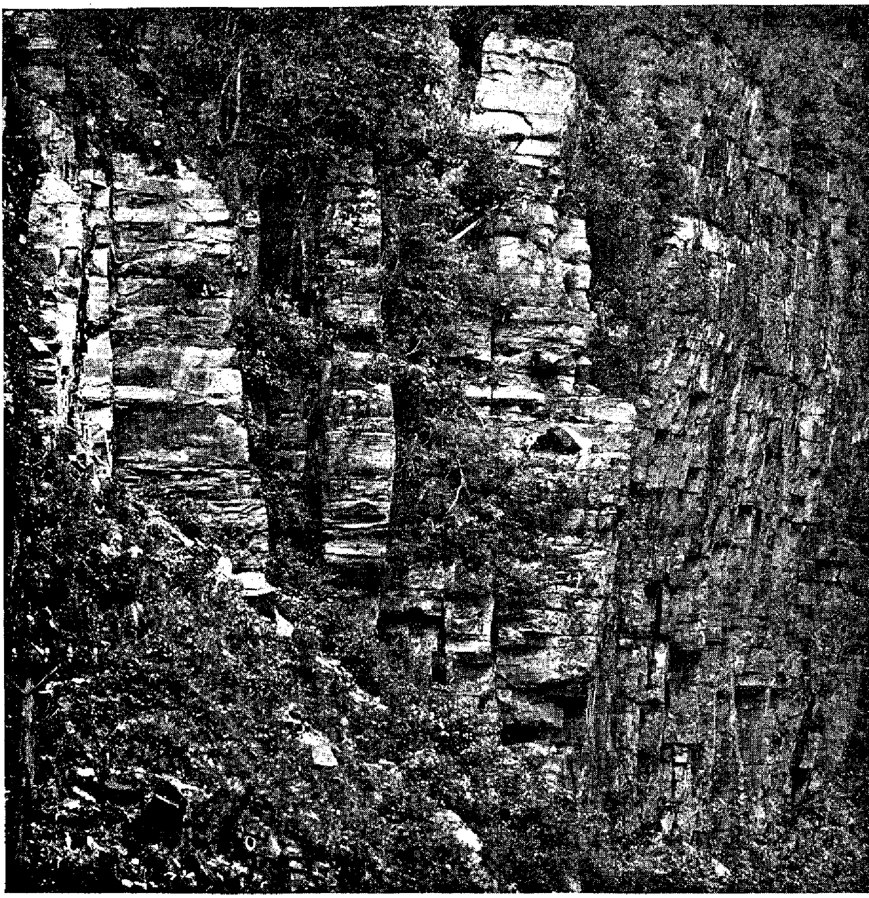

FIG. 54. Vertical joints in nearly horizontal Cambrian quartzite. One mile west of Poplar, North Carolina. (Keith, U. S. G. S.)

also the measure of its liability to disintegrate under atmospheric action.

Kaolin. Hydration is the process by which water enters into chemical union with various mineral substances; and as a whole, it is one of the most important processes of change taking place among the rocks. Not only the surface waters, but also the deeply circulating underground waters, are concerned in this change; and as hydration is always accompanied by an increase in the volume of the substances which take on the water, large physical effects are also accomplished in this way. One of the chief examples of hydration is the changing of the feldspars to *kaolin*, or clay; but this must be considered as a process by itself,

The feldspars readily cleave into blocks large or small; and water entering these fissures, which may be very fine and almost imperceptible, often carries with it carbon dioxide in solution. The CO_2 in solution effects the change of the feldspar into kaolin, or clay, according to the following equation:

$$\underset{\text{Orthoclase Feldspar}}{2KAlSi_3O_8} + \underset{\text{Water}}{2H_2O} + \underset{\text{Carbon Dioxide}}{CO_2} = \underset{\text{Kaolin or Clay}}{H_4Al_2Si_2O_9} + \underset{\text{Quartz or Silica}}{4SiO_2} + \underset{\text{Potassium Carbonate}}{K_2CO_3}$$

This process is known as *kaolinization;* and by it, a decrease of 54.44 per cent in volume is brought about, by the removal of the potassium carbonate, which is very soluble, and by the removal of the silica or quartz as well. Ordinary clay usually contains some quartz flour, iron oxides, and other substances, besides the kaolin, or pure white clay. This change of feldspar into clay is one of the most important chemical changes taking place under the processes of weathering, the kaolin thus produced being chemically a hydrous silicate of alumina.

Laterite. But in the moist, warm conditions of the tropics, the feldspars are not generally changed into clay, but into hydrous oxides of alumina, one of the chief of these being hydrargillite ($Al_2O_3 \cdot 3H_2O$). A mixture of such oxides of alumina is termed *bauxite.* If the decaying rock is basic, such as basalt, a considerable amount of iron oxide is set free, which then gives a deep red or brown color to the mass, and often forms iron nodules or concretions. The mass of disintegrated rock thus produced is known as *laterite.* This is one of the most widespread products of rock decay throughout the tropics; and in Brazil, it has been known to penetrate to a depth of 300 feet below the surface, the solid rock having disintegrated and decomposed to that depth. The silica accompanying this change is usually carried off and accumulates as separate masses of quartz, in the form of agate or chalcedony.

Opposite the mouths of the Amazon and other tropical rivers, the floor of the ocean is covered by a red mud which has been derived from the laterite found on the lands drained by these rivers. Many of the bright red rocks among the older geological deposits were doubtless formed in much the same fashion, so far as their color is concerned, as practically all of these rocks give proofs of having been formed under tropical or semitropical conditions. Red rocks are also being formed at the present time under the arid conditions of the deserts; but as we have no desert fossils throughout the whole range of the fossiliferous rocks, and as other conditions forbid the idea of deserts when these rocks

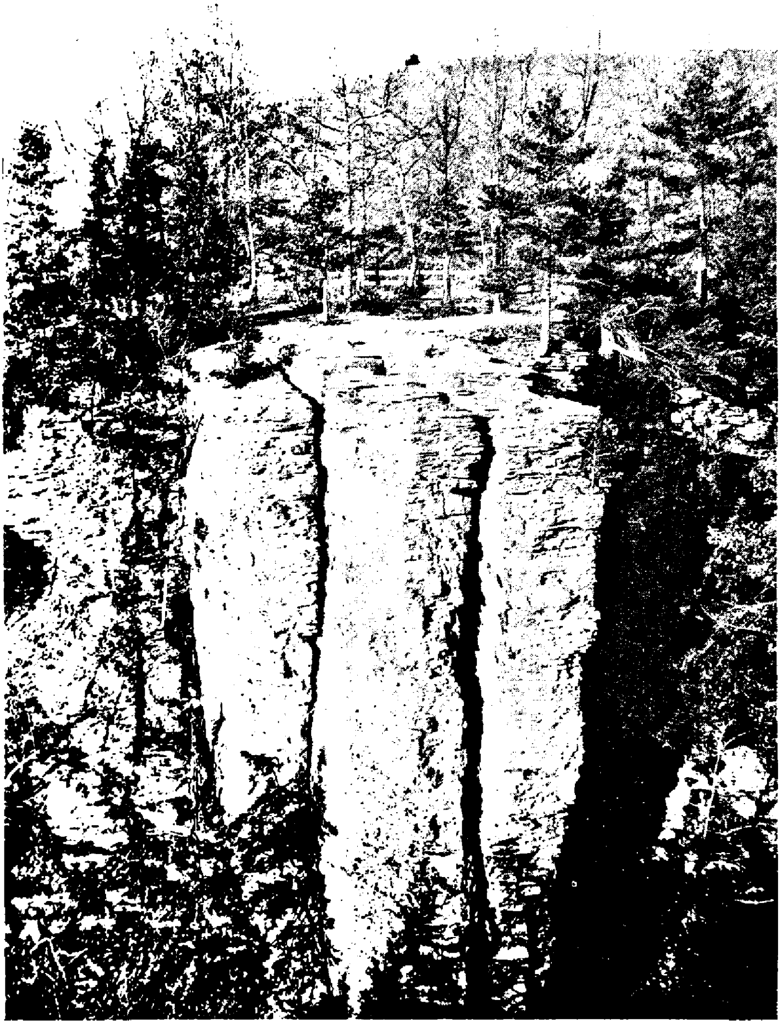

FIG. 54*a*. Buttress, illustrating vertical jointing, on the north wall of Fall Creek, Ithaca, New York. (Gilbert, U. S. G. S.)

were formed, it is more reasonable to suppose that these red rocks were formed under some such conditions as are now producing the laterite of the tropics. It has been estimated that laterite covers 49 per cent of the surface of Africa, 16 per cent of Asia, and 43 per cent of South America.

Other Rocks. Rocks which are largely composed of grains of *quartz,* or sandstone, may have their cementing materials com-

posed largely of limestone. Thus such sandstones are quite easy to decay; whereas sandstones with silica as the cementing substance are almost proof against the action of the weather. All limestones are easily eroded by water containing carbon dioxide, the limestone being converted into calcium bicarbonate, which is

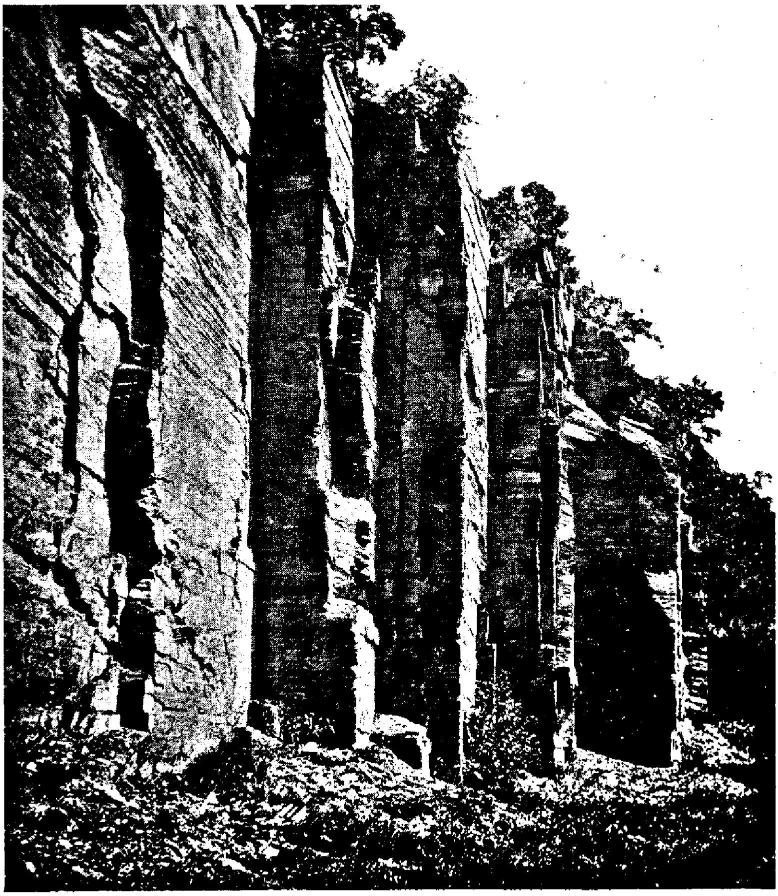

FIG. 55. Vertical jointing in Portage rocks (U. Devonian), East of Lake Cayuga, New York. (Kindle, U. S. G. S.)

readily soluble. This calcium bicarbonate, which is thus carried off in solution by the water, may be deposited in some other locality by precipitation from this solution, thus forming some new bed of limestone in another and distant locality.

In regions of scanty rainfall, like those of the Rocky Mountains, we often see the rocks and mountains displaying brilliant colors of yellow, orange, or even vermilion, these brilliant colors

being due to the presence of the oxides of iron which have been brought to the surface of the rock and there deposited in the form of ferric oxide. If the rainfall were more plentiful, the water would carry away these iron oxides as fast as they were formed, and thus these brilliant colors could not be produced.

Iron Ores. Large, thick beds of *limonite,* practically pure and sometimes 100 feet thick, are thought to have been produced in the places where we find them, by decomposition of other beds which once existed in these localities, such beds being originally composed of limestone containing iron carbonate (siderite). When such rocks are decomposed and the other substances are carried away by the percolating waters, the iron oxide which is left behind changes over into siderite or limonite, forming the immense beds which are often now the source of valuable iron ores.

It is supposed that when waters containing iron in solution come in contact with a large amount of decaying organic materials, these latter substances seize upon all the available oxygen in the solution; and thus the iron is deposited, not as an oxide, but as a carbonate.

In accord with this idea, it is a well-recognized fact that *siderite,* which is an iron carbonate, is commonly found in connection with formations which also contain coal or other organic materials.

But if there is not much decaying vegetation, the carbonate may be changed over into the oxide, and be deposited in the form of limonite, or yellow iron ore, which is often found in loose, porous masses near the margin of swamps or ponds, but is often absent near the middle. In some of the Swedish lakes, this bog ore has been known to form very rapidly, layers several inches in thickness having formed in twenty-six years. (Grabau.)

This change of iron carbonate into an iron oxide is largely accomplished by the so-called "iron bacteria," which are minute organisms present in many waters. In most instances, it is impossible to determine whether a certain iron deposit found in the rocks was formed by purely chemical precipitation, or by the agency of these bacteria; but it is known that bacteria are the active agents in many of these formations.

Large deposits of clay have been formed by the decomposition of quartzites or granites, the clays accumulating in basins or valleys by the action of streams which have brought them from the higher ground where they were made.

Arid Conditions. In arid regions, where lakes have been gradually drying up for centuries, the water becomes concentrated with certain minerals, and these concentrated solutions throw down precipitates of the substances which they hold, these

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substances being precipitated in a very definite order. *Gypsum* (calcium sulphate) is one of the first substances to be thus deposited; and large, thick beds of this material are thrown down by waters which contain it in solution, whenever these waters are concentrated by evaporation. After most of the gypsum has been deposited, other salts may be thrown down, *common salt* being one of the last substances to be dropped from such a solution.

As immense beds of both gypsum and salt are found in various parts of the world, these beds sometimes being many hundreds of feet in thickness, it has been commonly supposed that such deposits were originally formed by the evaporation of great inland lakes. That small deposits of these substances are now being formed where lakes are drying up, is undoubtedly true; but that all the beds of these substances which we find in the earth were formed in the long ago by a similar evaporation of huge lakes in arid climates, is merely an assumption. There is no proof whatever that they were formed in this way. It is quite possible that these beds may represent original formations of these materials which have since been covered by sedimentary rocks. Each particular instance, of course, would have to be decided on its own merits, according to the evidence available.

The Stassfurt Deposits. In the Stassfurt deposits of North Germany is a series of limestones and dolomite, followed by strata of anhydrite and gypsum some 300 feet in thickness, followed by salt beds over 1,000 feet thick. These latter are subdivided or interbedded by about 3,000 thin layers of anhydrite averaging about 7 millimeters in thickness, which have been called *"annual rings."* The alternating beds of salt average about 8.5 millimeters in thickness. Above these salt deposits are the salts of other minerals which have given these beds their great commercial value, these latter strata being from 200 to 300 feet in total thickness. Above these again is a second series of salt clays with various other kinds of salts containing the remains of marine animals, with some red clay beds forming the topmost deposit of all. Throughout the series, fossils are rare except in the basal limestones and in the salt clays near the middle of the whole series, though a few plant remains occur here and there through the other beds.

It has been thought that these beds were produced in a portion of the sea which had been cut off from the main body of the ocean and had gradually dried up during a long period of time. There seems a degree of plausibility about this theory; though the estimate of over 3,000 years, based on the number of so-called "annual rings," depends for its accuracy wholly upon the assumption that the changes represented by the alternations of the deposits were of *yearly* recurrence. If these changes took place

more frequently than once each year, the estimated length of time involved would be reduced in just that proportion.

This theory of the gradual building up of these deposits in a drying or arid climate of a cut-off arm of the sea, would also imply that these beds were not subsequently disturbed by the other geological changes. As a matter of fact, we do not really know how these deposits were formed. It is possible that they may have been produced by chemical precipitation from the waters of the ocean in some wholly different manner. The matter is too uncertain for us to base any very far-reaching conclusions upon our views of the way in which these deposits were formed.

Iron Bacteria. Within recent years, it has been proved that minute vegetable organisms living in water, which are known as *iron bacteria,* are the intermediary agents for the change of iron carbonate into ferric hydroxide, or limonite. These organisms secrete the iron from the solution and change it in their cells from the ferrous to the ferric condition, thus rendering the iron insoluble. As such changes are now going on in swamps and other bodies of rather shallow water, it is often assumed that *all* of the ancient deposits of similar iron ores were made in this way. This, too, is an unwarranted assumption. The chemical changes spoken of do go on in many instances without the presence of these bacteria; and these deposits which we find in the ancient rocks may, like the gypsum and salt, merely be the *remains of primitive formations.* In other words, while certain types of chemical processes are now known to produce these deposits of iron or gypsum or salt in a small way under modern conditions, yet it is not an assured fact that *all* of such substances which we find in the earth must have been produced in these ways. *The iron, the calcium, and the sodium and chlorine must originally have been in existence in some form or other;* and it is a wholly unwarranted assumption to suppose that all of these substances originally existed in solution in the sea water, and that they were gradually derived from the sea water a little at a time and then finally converted into the rocks as we find them now. This sounds too much like a modern revival of the old onion-coat theory.

Concretions. Waters which contain *limestone* in solution are often the means of consolidating masses of sand or gravel, or even of clay, because this limestone is very easily precipitated by partly evaporating the water in which it is contained. Often such precipitations of calcium carbonate take place around small grains of sand or other particles of matter, thus forming what are known as *concretions* (Fig. 35). Deposits of limonite may also

occur in beds of sand or gravel, thus consolidating them. But when *silica* is held in solution by the waters percolating through these beds of sand and gravel, the silica may also be precipitated and may form a cementing material by which the grains of sand are strongly held together. Such a cementation by means of silica makes the hardest and most enduring type of sandstone.

Precipitation of Calcium Carbonate. Recent studies have shown that the ocean water in general is saturated with calcium carbonate in solution, except at great depths and probably at the surface in the polar regions. As the larger part of the ocean is now intensely cold, any decided increase in the temperature of a portion of it, or any material amount of evaporation which might affect a portion of it, would cause a precipitation of the calcium carbonate held in solution. It is known that such *precipitation* does go on in parts of the ocean, as in the lagoons of the coral islands, though it is not precisely known how fast or how widespread such chemical deposits are now being made.

Oölites. Certain bacteria, called the *denitrifying bacteria,* which live in the warmer waters of the ocean, bring about the change of the nitrates held in solution, producing ammonia, which ultimately forms ammonium carbonate. The latter, by reaction with calcium sulphate in the sea water, produces a precipitation of calcium carbonate, which usually accumulates in spherical or elongated grains, forming the deposit known as *oölite.* Deposits of this kind are forming at the present time off the coast of Florida and near the adjacent islands.

Dolomites. Several kinds of *algæ* living in the ocean form precipitates of calcium carbonate in their tissues and as crusts on the outside. They generally go under the name of *nullipores;* and while they occur in the northern waters, they are most common in the tropical seas, where they comprise very important agents in the building up of coral reefs. Many reefs are more than half composed of limestones built by these organisms. Many or perhaps most of these lime-secreting algæ also separate out of the sea water a considerable amount of *magnesium carbonate* and form a precipitate of it in the same way that they form the calcium carbonate. In this way, limestones rich in magnesium carbonate are formed, and may become true *dolomite* in composition, the purity of the dolomite being assisted by the leaching or dissolving out of much of the associated calcium carbonate at some subsequent period, the proportional amount of magnesium carbonate being thus increased. It is possible that this will explain the formation of many of the ancient dolomites whose formation has been so long a puzzle to geologists.

CHAPTER VI

The Atmosphere as a Geological Agent

Results of Weathering. In the previous chapter, under the subject of chemical action, we have already considered some of the work done by the atmosphere. This work of the atmosphere in its chemical capacity in breaking up the solid rocks, with other agencies also which act together for the same results, is known as *weathering*. But there are other kinds of work done by the atmosphere which are of considerable geological importance, and these must now be considered.

The various kinds of rocks offer very different degrees of resistance to the action of the various agents of weathering. Differences in rainfall, in temperature, and in the direction and violence of the winds, result in many differences in the changes accomplished in the various localities. A protective coat of vegetation also offers a very material obstacle in the way of the action of the atmosphere.

When these various agents begin to work upon a level land surface, the first effect in *denudation,* or removing material from a part of the exposed surface, is to produce an increasing irregularity in the surface (Fig. 56). A land surface which is varied by hill and valley is said to possess *relief;* and when the various agencies of erosion have planed off all these irregularities, leaving only a flat or gently sloping surface which is but slightly above the level of the sea, such a land is said to have been reduced to the *base level of erosion,* or to be *base-leveled.* We should note in passing that such a condition of base-leveling is *an entirely ideal or imaginary condition of things,* since, except on the most minute scale, such an action of base-leveling has never in a single instance been observed as an actual fact. It is commonly assumed that such action of base-leveling has repeatedly occurred in past ages under the combined agencies of erosion; but there is no direct proof to this effect. The smoothing out of a wide area of unconsolidated materials by the action of a body of water standing above it, has often been seen. But we have no experience of seeing even a small area which has actually been leveled off by the ordinary agencies of subaërial denudation and erosion. In other words, subaqueous leveling is a well-demonstrated process; but subaërial base-leveling is quite hypothetical, and wholly undemonstrated objectively.

The general result of weathering is to accumulate masses of broken fragments about the base of the bare rock surfaces which

are exposed to the agencies of weathering. Such accumulations of fragmental material are termed *talus,* and they are seen in almost every locality where bare rocks are exposed to view. But as the rain and the winds, which are the mechanical agents of the atmosphere for removing fragmental material, are constantly engaged in carrying away these deposits of talus, the amount of

FIG. 56. Erosion following the removal of forest cover; Great Smoky Mountains, Tennessee. (U. S. Bureau of Forestry.)

this talus, called also *residual waste,* which we find in any particular locality, represents the balance between the work of weathering and the work of erosion and denudation.

Planetary Winds. The atmosphere as a whole exhibits certain well-marked forms of movement which are termed the *planetary circulation,* those members of this circulation which are near the surface of the earth being known as the *planetary winds.* Speaking broadly, the air in the vicinity of the heat equator tends to rise, causing calm, cloudy weather, with much precipitation. This produces a *belt of calms* all around the globe, which by the

sailors is termed the *doldrums*. Flowing in toward this tropical belt of calms from either side are the northeast and the southeast trade winds, these winds blowing with great steadiness.

North and south of the trade-wind belts are two other belts of comparative calm, known as the *horse latitudes*. In these regions, the high upper air is slowly settling, producing almost uniformly fine weather. North and south of these again (in each hemisphere) are the regions of the *prevailing westerly winds*, these regions of the westerlies being about what we usually call the north temperate zone and the south temperate zone respectively, these regions, however, extending even into the more extremely cold regions of the north and the south.

These planetary winds exert a profound influence on the ocean waters, producing or at least promoting the flow of the waters in those definite directions which we call the *ocean currents*. Both the planetary winds and the ocean currents form great circles moving according to Ferrel's law, clockwise in the Northern Hemisphere and anti-clockwise in the Southern Hemisphere. And in those localities where the winds are quite uniformly from one direction, very pronounced effects are to be seen in the drifting of the sand dunes and in the forms of atmospheric erosion exhibited by the rocks, as well as in the shape and location of the shore forms worn away by the ocean waves and currents.

Dust Storms. Wherever the winds are strong and the loose material on the surface of the ground is not held down by moisture or vegetation, the wind always carries vast clouds of dust and sand, whenever it moves at a rapid rate. Everyone who has traveled through the arid parts of the southwestern United States has had some experience with *dust storms*, as they are usually called. Such dust storms are of quite frequent occurrence; and in such places as the deserts of Southern California and Arizona, they often produce some very astonishing results. Tons of material have sometimes been piled up on the railway tracks or about lone railway depots, almost like drifts of snow, attaining a height of ten or twenty feet in a single storm. The sand blown by the wind acts like a natural sand blast, and near San Bernardino, in Southern California, has been known to cut the telegraph poles to such an extent that unless protected by piles of rock about their bases, they are soon entirely cut off. On ocean beaches also, the sand is carried by the wind to a considerable extent; but here the effects are much less pronounced than on the wide expanses of desert regions.

Dust storms have been known to carry material to very great distances. One such storm in China is reported to have extended over more than 450 miles at one time, and the materials gathered up were transported an immense distance. In February, 1895, an extensive fall of dust was observed in Missouri which must have come from Nebraska and Western Kansas, because all of the intervening country was at that time covered with snow and ice. It has been proved that a single storm carried more than a million tons of dust from the arid southwest plains region and scattered it over the region around the Great Lakes.

On April 2, 1892, there fell on the deck of a ship 95 miles southwest of Nagasaki, Japan, a cloud of yellow dust which must have come from the interior of China, at least one thousand miles distant. Dust storms have also transported materials from Australia to New Zealand, a distance of some 1,500 miles. Dust from the Sahara desert has been observed to fall in Northern Germany and England, representing a distance of over 2,000 miles. Volcanic dust which has been blown up into the high regions of the atmosphere has also been carried to great distances. On good authority, it is declared that the dust formed by the great eruption of Krakatoa, in the East Indies, in 1883, was carried up to such a height in the atmosphere that it was caught by the high air currents and carried completely around the globe before it settled. This dust is said to have made the entire circuit of the globe in 15 days.

Desert Conditions Peculiar to Our Age. It has long been believed that practically all of the stratified deposits formed in the olden time and now existing as the stratified rocks of all the continents, were produced by *water,* and largely by *ocean water.* But of late years there has been a marked tendency on the part of geologists to explain many of these deposits as having been due to the action of the winds. It has been pointed out that the winds produce deposits that are well assorted; that is, where the fine and the coarse materials are not mixed together in a heterogeneous mass, but the materials of one size are all together. Deposits formed by the atmosphere are also much inclined to be *cross-bedded* — a term which has already been explained. They are also quite markedly void of fossiliferous remains. Accordingly, when cross-bedded structures of well-assorted materials which contain no fossils are encountered here and there in the ancient rocks, the tendency now is to explain these deposits as having been formed by wind action in the olden time.

But it seems to the present writer that such a conclusion is not well justified. It may be quite difficult to distinguish beds formed

by wind from those formed by water under some circumstances; but the very fact that *we have not up to the present time found in the rocks any fossils similar to our modern desert life,* is good evidence to my mind that in the stratified deposits with which

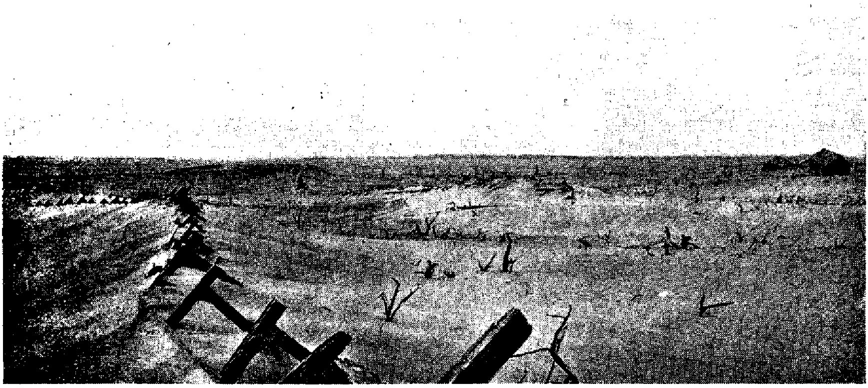

FIG. 57. Shore sand dunes and artificial breaks, Beaufort Harbor, North Carolina. (Holmes, U. S. G. S.)

geology deals we do *not* have any considerable amounts of strata made by the wind, if indeed we have any at all except those surface deposits on all the continents which have been formed in comparatively recent times, or since the other geological deposits

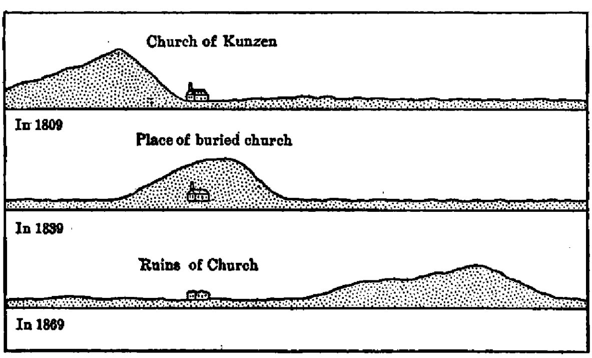

FIG. 58. Diagram to illustrate the migration of a sand dune during 60 years. On the east shore of the Baltic Sea, near the village of Kunzen. (From Berendt.)

were laid down. "No fossil remains of desert plants have yet been recovered." (D. T. Macdougal.) In fact, it seems to me that desert conditions such as we know at the present time are *peculiar to our present age,* and that in ancient times, not only was the climate more mild and equable, as we shall see from

evidence a little later, but desert conditions like those of the present time were as wholly unknown as were the frozen regions of our present arctic climate.

Dunes. *Sand dunes* are heaps of sand, much like drifts of snow, which are found along all the coasts except the steep, rocky ones, these dunes being formed by the winds, and burying trees, houses, and fertile lands as they gradually travel inland. They abound on the shore of the Bay of Biscay, in France, extending along the coast for some 200 miles, and covering a strip from

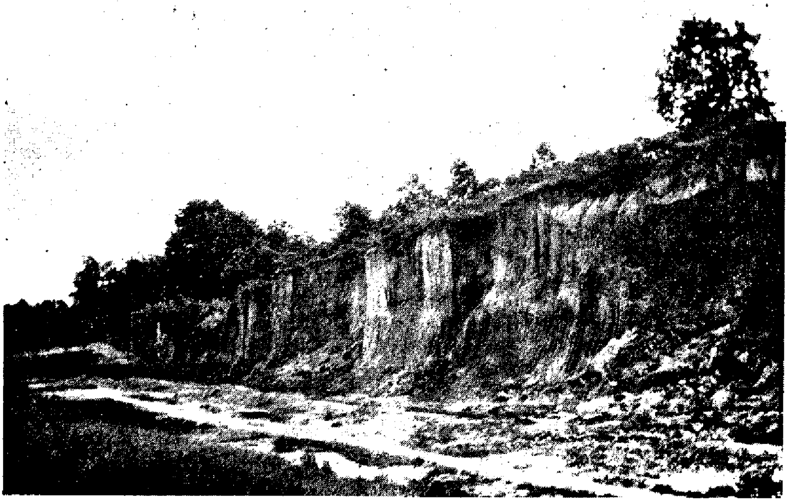

FIG. 59. Banding in loess, at railroad cut east of Wynne, Arkansas. (Fuller, U. S. G. S.)

3 to 6 miles wide. Some of these dunes, or sand drifts, are over 100 feet high, the highest of strictly *coastal dunes,* though the dunes of the Great Lakes in America, and of the deserts in all parts of the world, are sometimes much larger than even these. Dunes abound also along the coast of Belgium and the Netherlands, the Danish coast of the North Sea, and the south coast of the Baltic; and in almost all these instances, the sea seems to be very rapidly encroaching on the land, eating away at the coast, and gradually working farther and farther inland.

Desert dunes are plentiful in the mountain plateau region between the Rockies and the Sierra Nevada Mountains, in the Colorado and the Mohave deserts of Southern California, and even in Nebraska and other States just east of the Rockies. Large areas in European Russia are covered with dunes, as are

also immense areas in the arid parts of Asia, Northern and Southern Africa, and Australia. One third of the entire surface of Arabia is said to be covered with these rolling and constantly changing hills of sand.

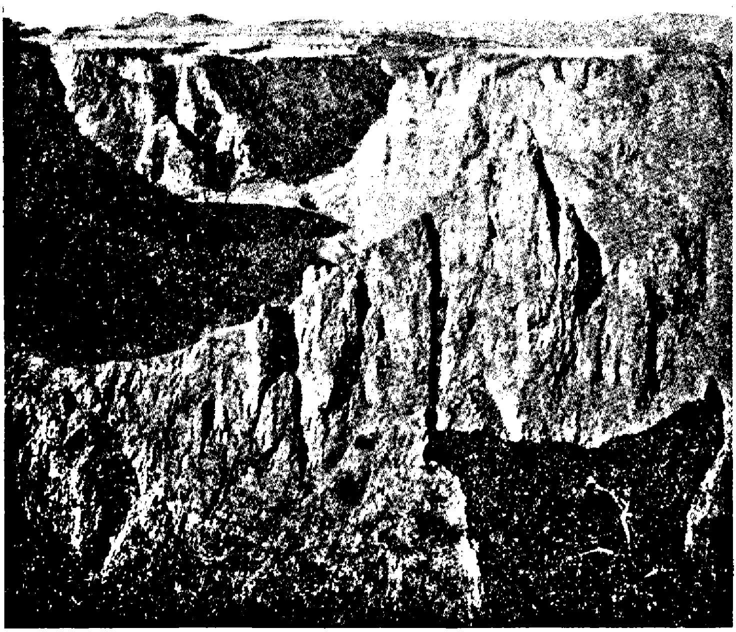

FIG. 60. Loess deposits, North China. (After Willis.)

Loess. Large areas on all the continents are also covered with a peculiar deposit called *loess,* which is generally thought to have been formed by the winds largely or almost wholly; though this point is much disputed.

The typical loess is composed of very minute angular (not rounded) grains of silica which form a loamy silt containing much calcareous matter. It is finer than sand, but coarser than ordinary clay, though it resembles the latter much in texture. It

is of remarkably uniform mechanical make-up, and is usually devoid of any visible stratification. It seems almost to be jointed, like many solid rocks; for it breaks off in large upright slabs, thus leaving abrupt cliffs which are a very striking feature of the landscape where they occur (Fig. 59).

Loess was first described from the Rhine Valley, but later it was also found over large parts of the Mississippi Valley, over

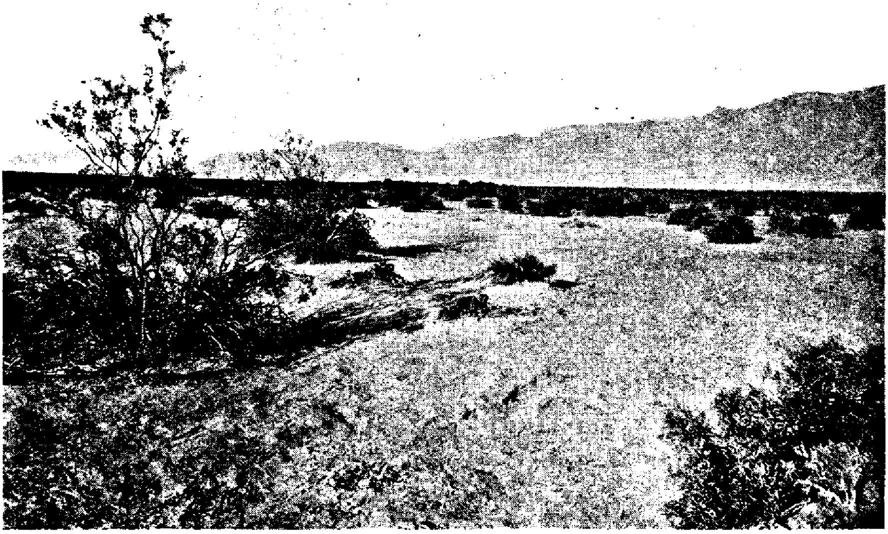

FIG. 61. View across Death Valley, California. There is every evidence that this basin, like others elsewhere, was once full of water. (Gale, U. S. G. S.)

much of Southeastern Europe, and especially in China. In the latter country, the loess beds occasionally have a thickness of over a thousand feet; and they are thought to have been formed from the materials brought by the winds from the great desert of Gobi, in Central Mongolia. These loess deposits abound along the Yellow River and its branches, the high vertical bluffs formed by the loess being characteristic of this region. "Millions of Chinese live on the valley floors of dissected basins of this kind, for the loess is extremely fertile where well watered. Great numbers of people inhabit cavelike dwellings excavated in loess bluffs; in a thickly populated district not a house may be seen. The yellowish color of the loess prevails everywhere. It gives

color and name to the great river of the region, and to the sea into which the river flows." (Davis.)

The fossils of the loess are scanty, and consist chiefly of land snails, such as *Helix, Pupa,* and *Succinea,* with shells of ponds or lakes, such as *Planorbis* and *Paludina.* Bones of land vertebrates also occur, with roots and stems of grasses and other plants, the latter more or less mineralized.

Such fossils make it difficult to believe that this loess is a typically desert formation. And the fact that the regions where we find it are not in any sense deserts at the present time is an-

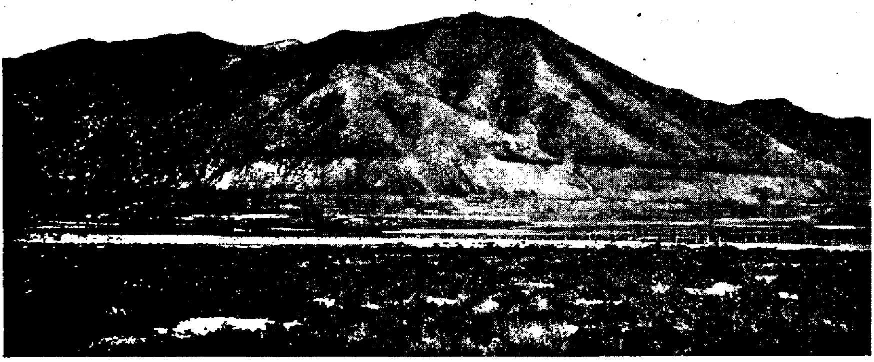

FIG. 62. Old shore line or terrace of Lake Bonneville, 3 miles north of Tooele, Utah. (Walcott, U. S. G. S.)

other argument of like nature; for there is no well-authenticated instance of any region which has once been a desert ever becoming anything else through a natural increase of the rainfall, though there are plenty of instances of the reverse, that is, of fruitful regions having become progressively so dry as to turn into typical deserts.

On the hypothesis of a great universal Deluge, we must suppose that great areas which are now largely desert were immediately after the Deluge *full of water;* for such areas are almost all of them *basin-shaped.* On this hypothesis, the lands to the *east* of such water-filled basins, at least in the region of the prevailing westerly winds, must for centuries have had a much greater rainfall than at present. But we must remember that all of the lands had been (on this hypothèsis) wholly stripped of

their vegetation, and must have remained thus denuded for a long period subsequent to the emergence of the continents.

Now it is a remarkable fact that the regions of the loess are found chiefly *to the east* of such basinlike depressions, now deserts, and in the path of the prevailing westerly winds; and it is reasonable to suppose that where we now find the loess, the winds for many centuries were far more uncontrolled in drifting clastic material than they are to-day in the same regions, for these regions are now covered with more or less of a full mantle of vegetation. But at the same time, the climate was not that of a desert, but probably well watered; and this peculiar combination of conditions may have been the cause of the production of this admittedly peculiar material, which has occasioned much discussion and dispute as to its origin.

However, the loess is conspicuously absent from those regions toward which the winds of the Sahara blow; and accordingly we must suppose that the materials of the loess are not found over the wide expanse of the Sahara and Arabia.

CHAPTER VII

Running Water

The Rainfall. Under the term *rainfall* is included all the water that is precipitated to the earth in any form whatever, whether as rain, or snow, or even common dew. Along the Atlantic seaboard of North America, the rainfall averages about 40 inches a year. In the plains region, it is 20 inches or less; while in the Great Basin between the Rockies and the Sierra Nevada Mountains, it is usually less than 10 inches. Regions where the

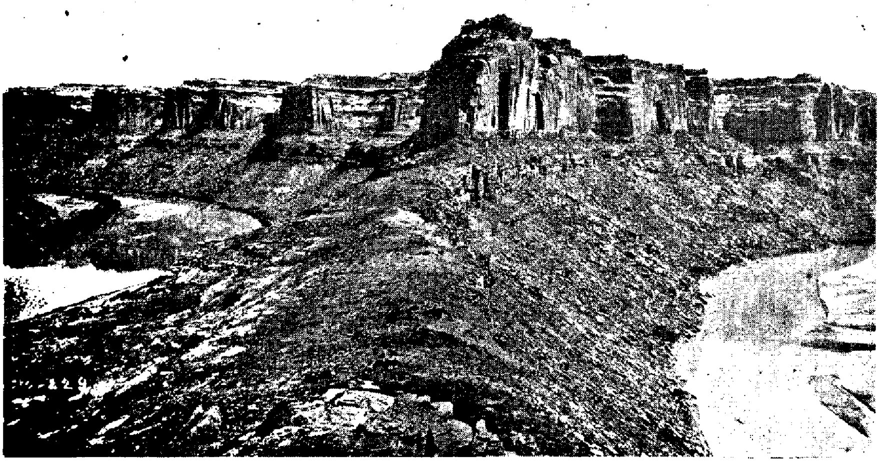

FIG. 63. Labyrinth Cañon of the Green River, Wyoming. On the dividing ridge at Bowknot Bend, looking up the river on the left, and down on the right. It is 6 miles from the one point to the other, following around the course of the river. (Beaman, U. S. G. S.)

rainfall is 10 inches or so a year, are termed *desert;* and even where the precipitation is not more than 20 inches, the climate is termed *arid* or *semiarid.*

In the northwest corner of the United States, the rainfall is often 100 inches a year; while in some parts of the tropics, this amount is much exceeded. In Java, the mean or average rainfall is given as 110 inches; in Sumatra, as 130 inches; in the mountains of Burma, as 160 inches; while in the hills of Assam, at the head of the Bay of Bengal, at the altitude of nearly a mile, the rainfall reaches the almost incredible average of between 400 and 500 inches a year.

The Run-Off. The amount of the rainfall which is carried away from the surface of the land is termed the *run-off;* the

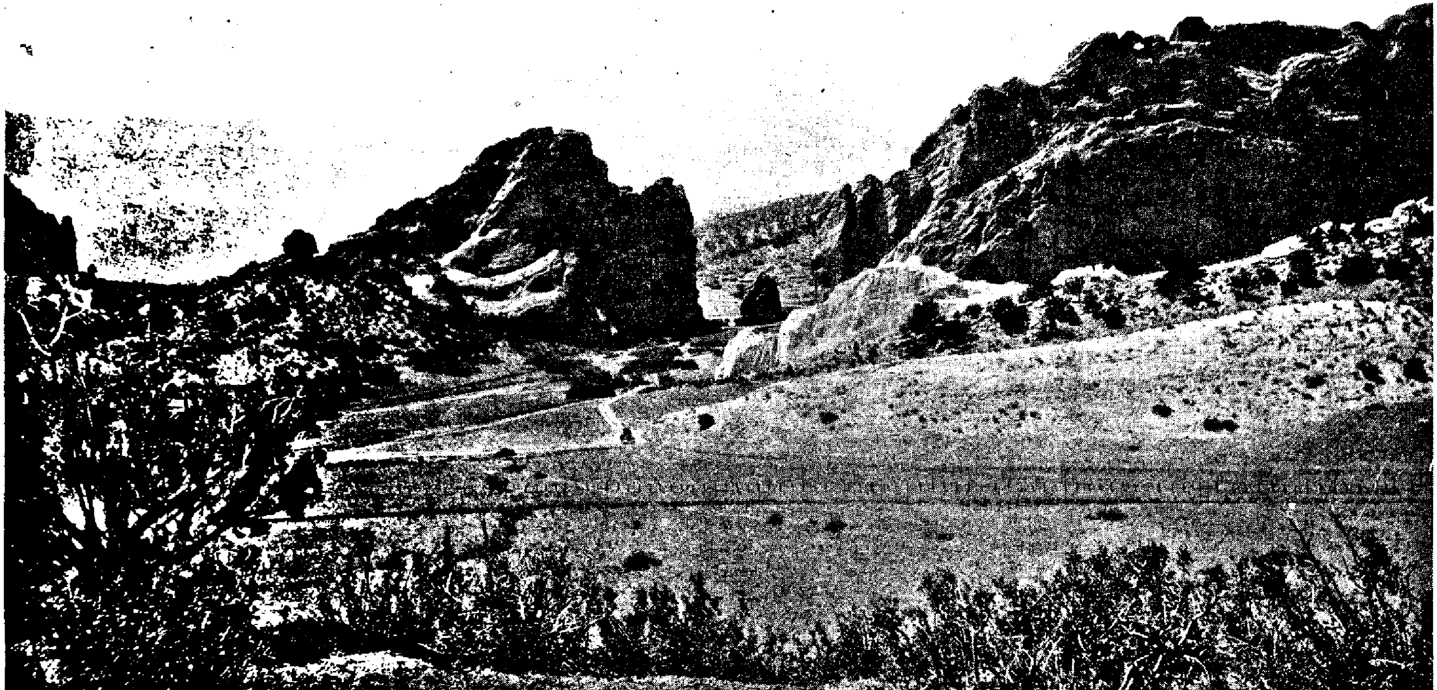

FIG. 64. Gateway to the Garden of the Gods, Colorado. These rocks are red sandstones. (Darton, U. S. G. S.)

remainder either evaporates or soaks into the ground and becomes *ground water*. The latter will be considered in the proper place. Here we are concerned to study what this run-off does in the way of geological work as it travels toward the sea. Murray has calculated that the total annual rainfall on the lands of the globe amounts to about 29,000 cubic miles, and of this about 6,500 cubic miles, or about one fifth, composes the run-off. As this run-off is working its way toward the ocean, it picks up and carries along with it an immense amount of earthy matter, partly by dissolving it and carrying it in *solution*, partly by carrying it in *suspension*, and also by the mere mechanical process of *rolling* particles along the bottom of its channel. Some of this load it drops at various places along the way, forming extensive river or lake deposits, which have characteristics of their own by which they may be identified with considerable certainty. But part of the load carried by the run-off ultimately finds its way to the ocean, where the mechanical part of it is dropped on the continental shelf near the mouth of the river. Even the portion of the load held in solution may be partly precipitated under certain circumstances; if the river happens to flow into a lake in an arid region, or even if it flows into some portions of the sea; but in general, this matter held in solution merely adds to that great accumulation of every mundane substance which we find in the waters of the ocean in some form of solution.

The effects of rain water in eroding a hill or other surface which is not well consolidated, are familiar to most of us. We are also familiar with the fact that a mantle of vegetation, especially a thick forest growth, almost entirely prevents erosion by the rains (Fig. 66). In forested lands, the rainfall is retained and allowed to pass off so slowly that floods are unlikely to occur in the spring of the year; while in regions of little forest cover, especially if the hillsides are steep, very destructive floods are liable to occur, as in the upper waters of the Ohio. The removal of the forests from a region has often resulted in the rapid erosion and loss of much of the soil of these lands, illustrating one of the great wastes of modern civilization.

Erosion in Arid Regions. In regions of dry climates, the effects of erosion are easily seen and are extremely characteristic. There is probably no region with absolutely no rainfall, and in those parts where the precipitation is very slight, it usually occurs fitfully in the form of violent downpours, or "cloud-bursts," as they are commonly called. Such cloud-bursts are generally of very limited horizontal extent, perhaps less than twenty or thirty miles in areal or horizontal diameter; but they have been known

FIG. 65. "Teapot Rock," an outlier, near Green River Station, Wyoming. (Jackson, U. S. G. S.)

to result in a maximum precipitation of over ten inches of rain in twenty-four hours. The erosion resulting from such downpours is much greater in arid regions than elsewhere, because the percentage of run-off is increased, and because the soil in such regions is already filled with air instead of with water, which prevents the entrance of more water when a surface film of the soil has once become wet. As vegetation is almost entirely lacking in such regions, this lack also helps the erosive powers of the

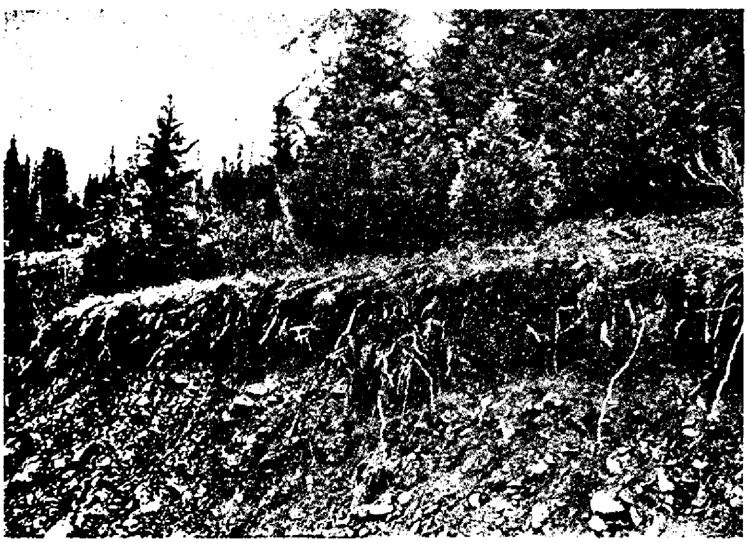

FIG. 66. Illustrating the very important part played by the roots of trees in holding the soil in place. San Juan Mountains, Colorado. (Fairbanks.)

water. Throughout the western part of the United States, these picturesquely eroded hillsides are very frequently seen. In some parts, they form what are called *bad lands*, because of the difficulty experienced in crossing the gullies made by the erosion of the streams.

In the desert regions of all parts of the world, we find rock deposits formed under the action of the streams produced by the violent downpours of these regions. These deposits strongly resemble in their coarseness and in the angular character of their contents the traditional kind of deposits formed by glaciers. No less an authority than Grabau declares that "often the structure is *suggestive of morainal accumulation.*" This author describes these deposits further as follows: "Large and small, round and angular blocks abound in the sandy ground mass with a total absence of sorting, the result of the indiscriminate piling together of the material by the tremendous flood rains of the desert. The evidence of violent impact is

further shown by the abundance of concussion marks and the total absence of the woody vegetation which is ground to fragments and washed away by the floods." ("Principles of Stratigraphy," page 542.)

Mountains of Erosion. In numerous parts of the plains country just east of the Rocky Mountains are many erosion remnants or beehive-shaped mounds which are the remains left after the surrounding materials have all been carried away by the erosive action of the winds or the waters, or by both combined. The famous Garden of the Gods, near Pikes Peak, Colorado, shows many very wonderful monuments of hard rocks which have been left standing in striking forms (Fig. 64). The various *buttes*, found in many places over all this region east of the Rockies, are composed of horizontal strata which have been left in a rounded, sugar-loaf form standing alone on the plains. Some of these isolated masses have broad and comparatively flat tops, and are termed *mesas*, from a Spanish word meaning *table*. Such mesas are generally capped by a layer of hard rock, which has protected the softer underlying strata. It is an impressive sight to see such a mesa or a butte rising for many feet above a great plain with its strata in a horizontal position, and to realize that all of the country, perhaps as far as the eye can reach, must at one time have been filled up with rock material at least as high as the top of this solitary monument, and that all this surrounding material has since vanished and been carried away by the waters. A fact which often makes such a phenomenon more impressive is that, in very many instances, for water to flow around such a lone monument at the present time would require that the whole country for a thousand miles must be submerged under the waves.

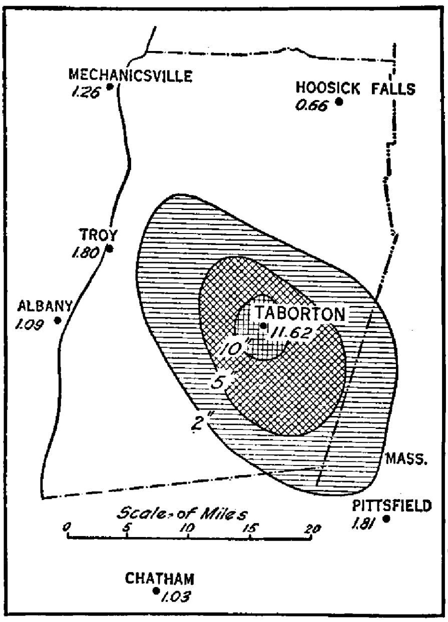

FIG. 67. Map of a "cloud-burst," near Taborton, New York, on August 10, 1920. The figures indicate the amount of the precipitation in inches. It will be noted that at the center of the storm, the precipitation was almost a foot for the 24 hours. (The Monthly Weather Report Review.)

However, no long ages of time are necessarily indicated by even this prodigious amount of erosion. We have only to suppose that the waters of a *retreating ocean* once flowed over these regions, while the strata of the rocks were still more or less freshly laid and still quite *unconsolidated,* to understand how all this vast amount of erosion might well have taken place in a very brief space of time, the present diurnal action of the elements merely finishing what was chiefly accomplished under quite different circumstances.

Speaking broadly, of course, we may say that practically all the mountains, except those of volcanic origin, are *mountains*

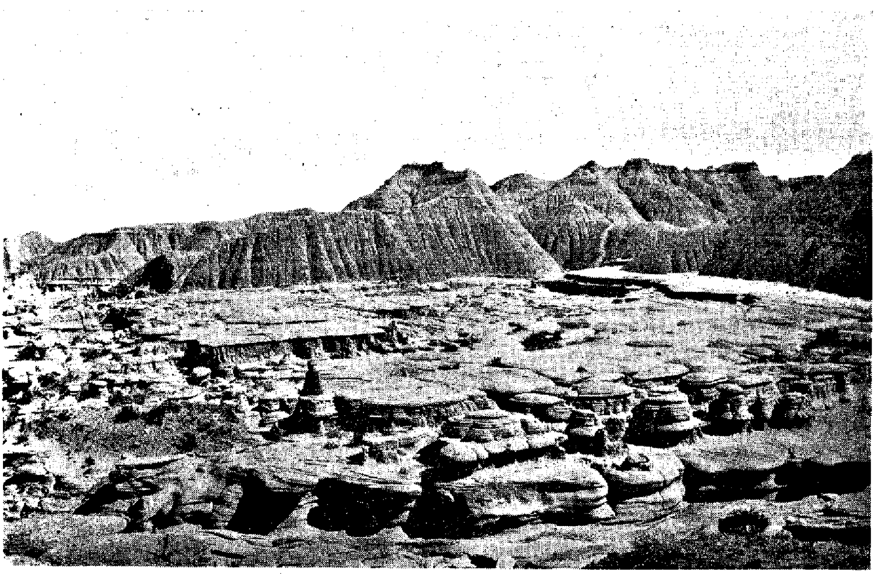

FIG. 68. "Toadstool Park," 3 miles northwest of Adelia, Sioux County, Nebraska. Bad Lands. Evidently the eroded bottom of an old lake. Note the marked difference between the erosion forms in this lake bottom and those of the surrounding hills. The hills represent the "Bad Lands." (Darton, U. S. G. S.)

of erosion; that is, they owe their present form largely to the eroding effects of the elements, many of them being composed of strata still comparatively horizontal, which may have extended out on all sides to a quite indefinable distance. However, in the great majority of such instances, it would be quite impossible to prove that the mere continuance of the amount of erosion now going on could have produced this present visible result, even if we prolong this present action of the elements to any reasonable length of time in the past. On the contrary, almost all the mountains, in their valleys and in their general features, are more easily explained as having been at least partly sculptured out by masses of water which once stood or

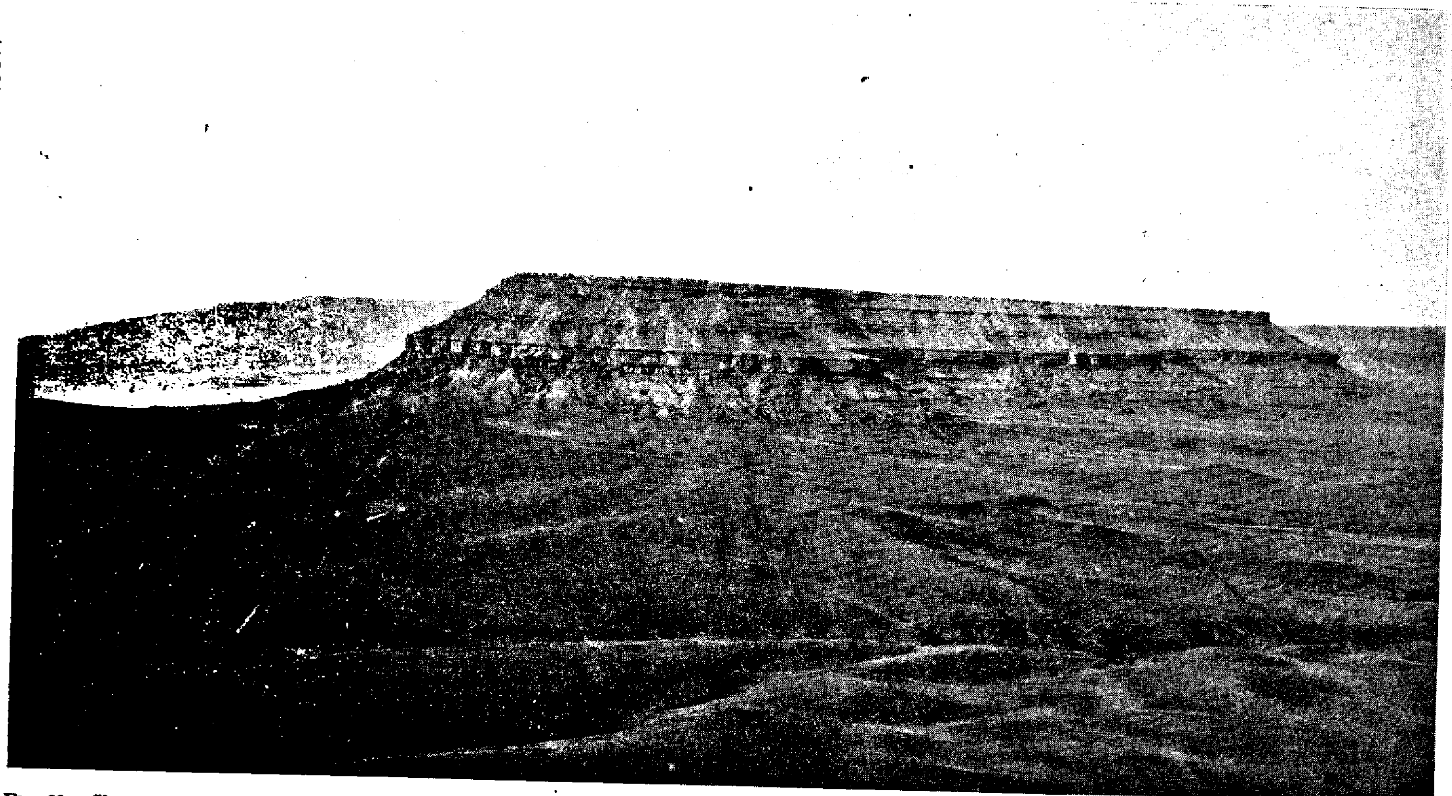

FIG. 69. Chugwater red beds (Permian-Jurassic), east slope of Big Horn Mountains, Wyoming. Looking north. This mass was doubtless once an island. (Darton, U. S. G. S.)

flowed around them, these waters in many instances evidently having done much of their work upon the strata while the latter were still comparatively soft and unconsolidated. And while this subject is easily capable of endless discussion, and perhaps incapable of definite settlement when considered by itself alone, yet, as must be confessed, the catastrophic interpretation of these problems has many strong arguments in its favor, and when considered in connection with the other geological arguments, seems quite unanswerable.

Erosive Power of Moving Water. Clear water, whether of the streams or of the sea, has practically no power of eroding

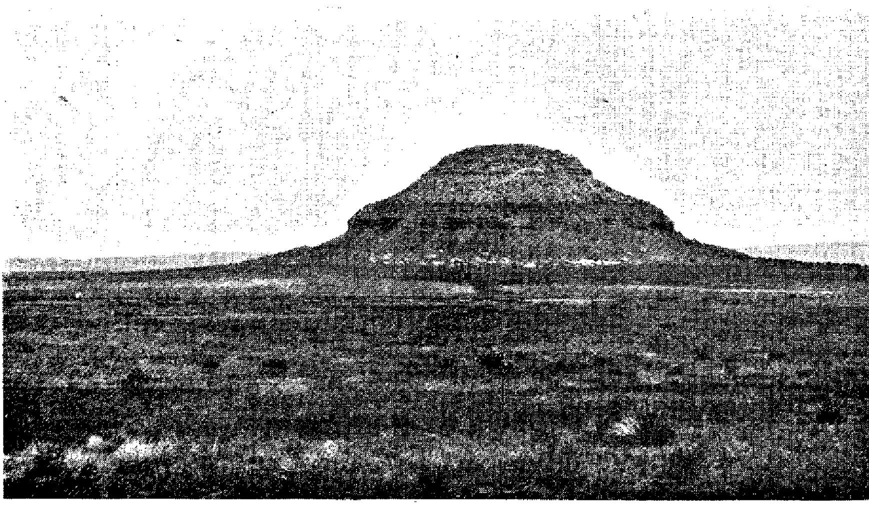

FIG. 70. Bell Butte, near Bell Ranch, New Mexico. (Lee, U. S. G. S.)

the surface of the compact rocks over which it flows. This is manifest by the many streams flowing in mountain districts at a rapid rate which pass over stones completely covered with plant growth. On many seacoasts also, the rocks are covered with a coat of seaweeds, even though the tide and the waves pass rapidly over these rocks many times a day. These coats of vegetable matter could not possibly exist if the waters were eroding the bottoms or the banks where they are situated.

On the other hand, when a river is *carrying mud or sand or gravel* in its course, it uses these materials as tools with which to dig out a deeper channel for itself. Such a river, when dragging along rock materials over the bottom of its channel, has been compared to a "sinuous, flexible, and endless file, ever moving forward in one direction, and by means of the moving

FIG. 71. Rainbow Bridge, viewed from the south. San Juan County, Utah. Composed of La Plata sandstone (Jurassic). Height, 398 feet; width between abutments, 278 feet; causeway at top, 33 feet wide. (Gregory, U. S. G. S.)

sand or gravel rasping away the country rocks beneath and beside it, thus cutting an ever-deepening trench." (Pirsson.) When standing on the banks of some mountain stream in flood season, one can often feel the ground vibrate, as the large rocks carried along in the bed of the stream are pounded against one another in the bottom of the torrent, such friction result-

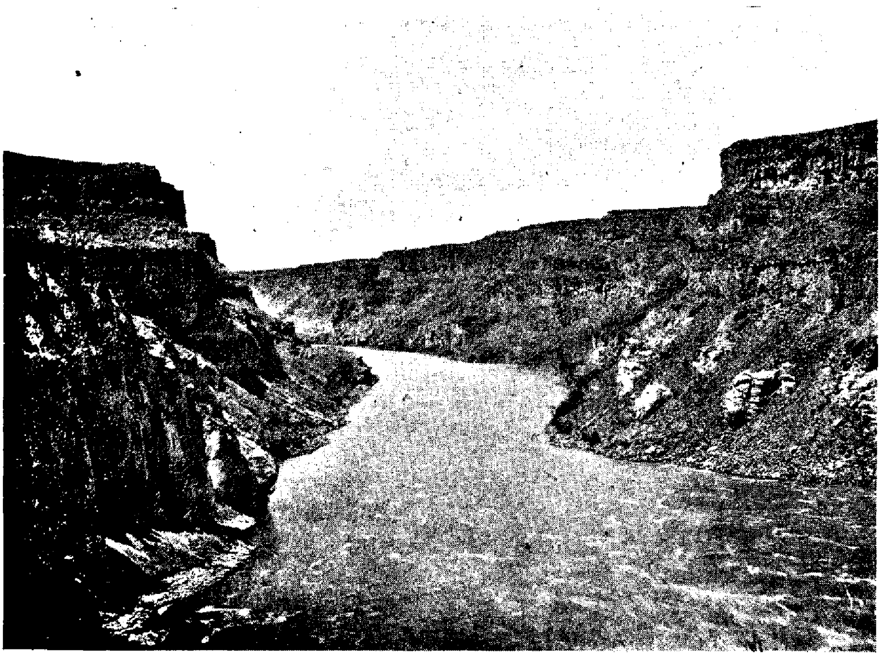

FIG. 72. Cañon of the Snake River, below Shoshone Falls, Idaho. The wall rocks are volcanic. (Gilbert, U. S. G. S.)

ing in a very great and rapid decrease in the size of these rock fragments as they work their way down the river.

Flowing waters, whether in the form of streams or in the form of waves and currents along the shore, take advantage of the joints with which all rocks are intersected, to loosen and move the blocks of rock formed by these joints. This process of picking out joint-blocks or other pieces of rock, is known as *plucking*, or it is spoken of as the quarrying power of a stream or current. Such plucking or quarrying is also performed by glaciers.

When a stream is not overloaded with material which is being transported, an increase in the rapidity of the current will enable the stream to erode still more rapidly. In fact, the

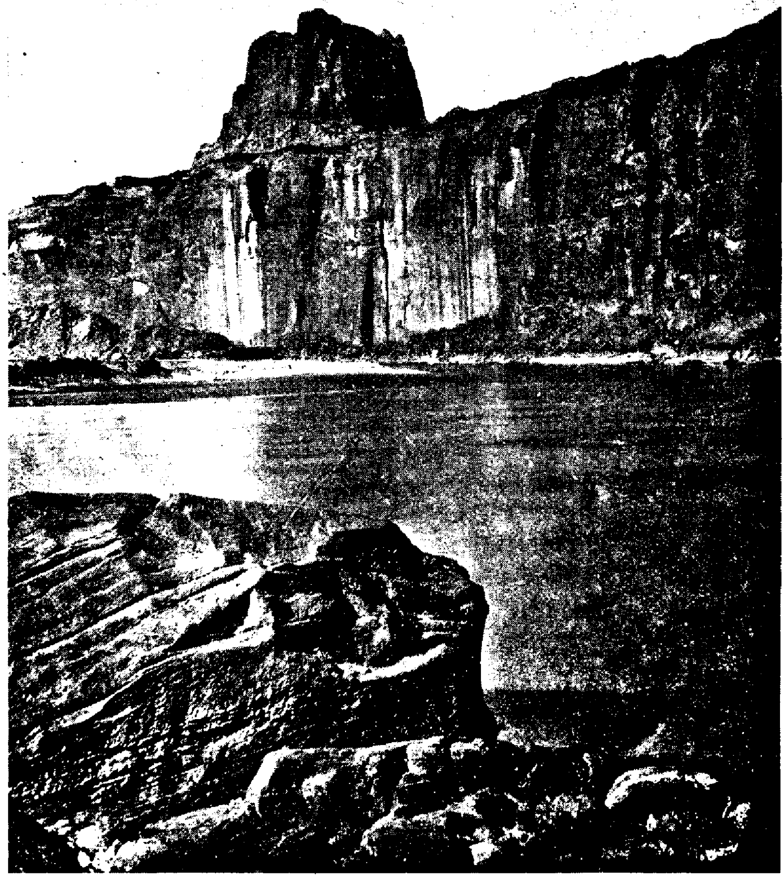

FIG. 73. Glen Cañon of the Colorado River. (Hillers, U. S. G. S.)

erosive power of a current varies as the *square of the velocity,* when the size of the rock fragments is equal and when they are present in the same proportion. Thus if the velocity of the current is doubled, the erosive power (from this cause alone) will be *four* times as great; or if the velocity is three times as great, the erosive power will be increased *nine* times.

However, another factor enters into this problem, greatly complicating it. This other factor is that the transporting or moving power of a current *varies as the sixth power of its*

velocity. This can be illustrated by the following diagram, which has been taken from Pirsson.

If we start with a current which has just sufficient power to move a cube a, and if this current is doubled in velocity, it can then strike one end of such a cube with a force four times as great as before, according to the

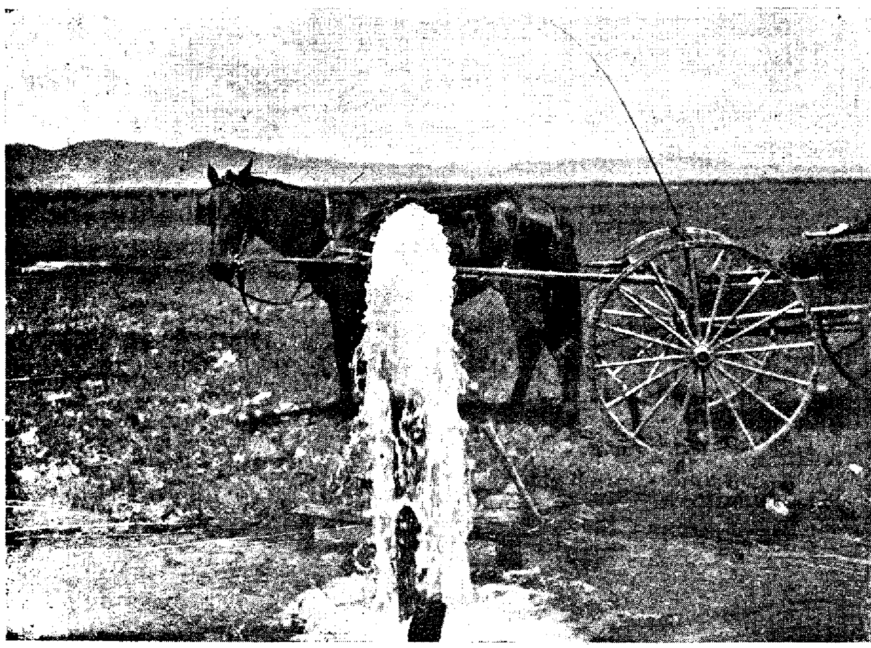

FIG. 74. Artesian well, San Luis Valley, Colorado. (Siebenthal, U. S. G. S.)

rule already given. This would be obvious from the fact also that, with this increase in velocity, twice as much water would strike the face of such a cube, and each particle of water would have twice the velocity. Such a current moving now with a power four times as great as before, would be able to move four such cubes, a^1 a^2 a^3 a^4, placed one behind the other in a row. But clearly if sixteen rows of such blocks were piled up together, we should have a cube which would be sixty-four times as great as the small cube with which we started; and it is equally clear that this increased current striking on the face of this large cube A would move it just as the first current moved the small cube a. And this larger cube is just *sixty-four*

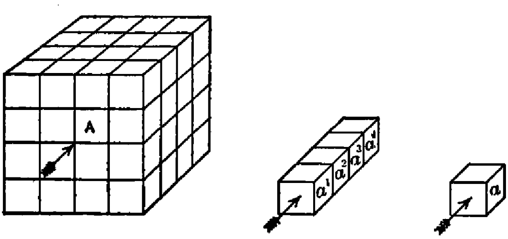

FIG. 75. Diagram to illustrate the fact that, if the velocity of a stream is doubled, its transporting power is thereby made 64 times as great. (After Pirsson and Le Conte.)

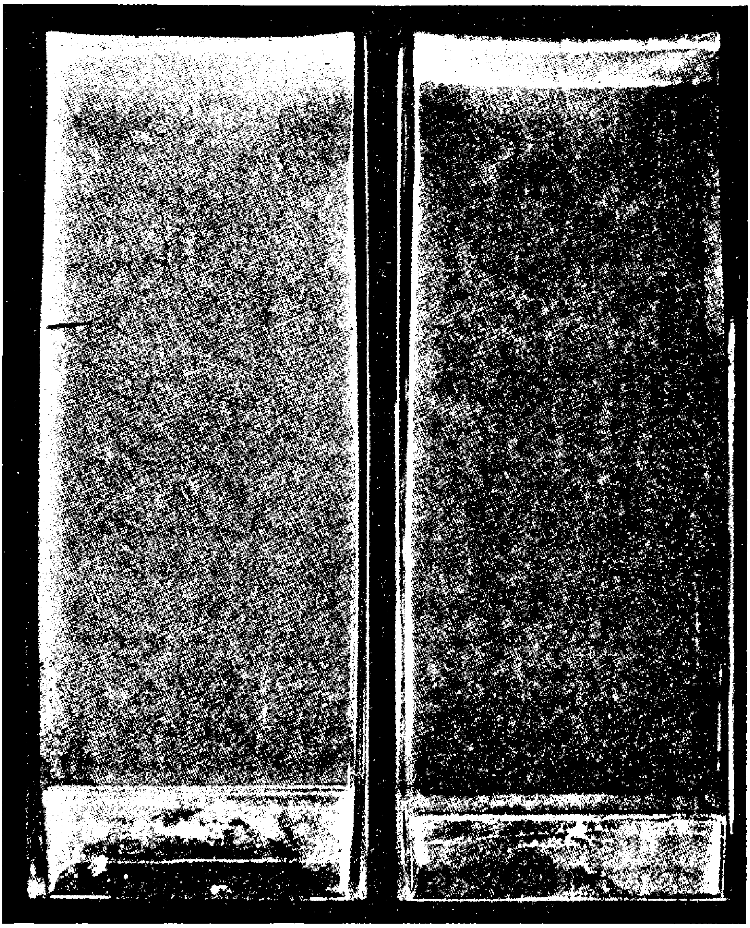

FIG. 76. Two containers, illustrating the settling of clay in salt and in fresh water, after 24 hours. The jar containing the salt water is clear, while that containing the fresh water is still turbid. (After W. B. Scott.)

times as great as the small cube; while *sixty-four is the sixth power of two.* Thus we see that the *transporting power of a current increases as the sixth power of its velocity.* Expressed as a formula, it would be $T = V^6$, where T = the transporting ability, and V = the velocity. If the velocity of the current be trebled, then its transporting ability will be 729 times as great as before, since 729 equals the sixth power of three. And if the velocity is increased 10 times, its transporting power becomes 1,000,000 times as great. And we must remember that this increase in transporting power also affects the erosion power of the waters, so that our formula for estimating the erosive power of water will now be that it varies *somewhere between the square and the sixth power of the velocity.*

It has been found by observation that when a current is running a fifth of a mile an hour, it will carry fine clay. When

it flows half a mile an hour, it will transport sand. A current of a mile an hour will roll along gravel of medium size, while one flowing two miles an hour will sweep along pebbles of the size of an egg over a comparatively smooth surface. But a current of fifteen miles an hour would move blocks of similar form weighing 56 tons or more; and a current of twenty miles an hour would move blocks weighing 320 tons. A current of water moving with the velocity of the wind in a storm would be capable of almost digging out the very mountains themselves by the roots.

The Assorting Power of Water. The power of a current of water to *assort* the materials which it is carrying, and to lay down coarse materials of about one size in one locality, while it carries finer materials farther on and lays them down in another place, with still finer sediment carried still farther and laid down in an entirely different place,— this ability of moving water to assort its materials is the explanation of the fact that we so often find a bed of sand consisting of grains of about one size in one place, and a bed of fine clay or mud in a distant place.

It has been found that river waters, such as those of the Mississippi, may carry muddy sediment in suspension for months or years, there being little practical difference between

FIG. 77. An overloaded, or aggrading, stream. Matanuska River, Alaska. (Mendenhall, U. S. G. S.)

such finely suspended material and the material carried as a true solution. But if such waters holding clay in suspension are *mixed with salt water* and agitated as by the waves, the clay quickly coagulates or forms into minute lumps, and is rapidly precipitated to the bottom, thus leaving the water clear within a very few hours (Fig. 76). This is the explanation of why the muddy waters of such large rivers as the Mississippi and the Amazon never are observed very far out in the ocean, for

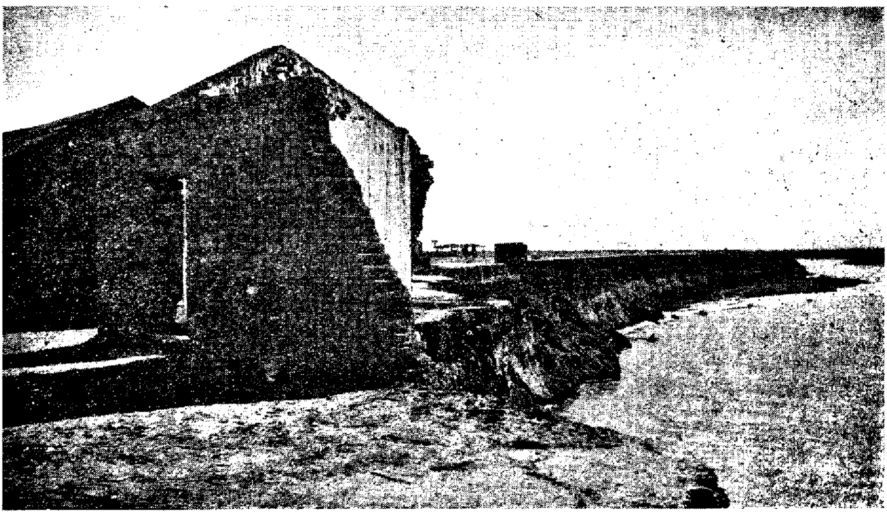

FIG. 78. View of the newly cut gorge of New River, and wrecked buildings, Mexicala, Mexico. 1906 — after the Colorado River had broken through and had been flowing in this channel for a few months. (Mendenhall, U. S. G. S.)

all their suspended load of sediment is quickly dropped on reaching the sea, and is not carried out beyond the edge of the continental shelf.

It has been estimated that the Mississippi annually carries about 340,000,000 tons in *suspension* in its waters, and more than a third as much more in the form of true *solutions.* All of these materials have been gathered up by the waters of the river in flowing over the land. On this basis, estimates have been made of the length of time which such transportation would require in order to lower the level of the Mississippi Valley to the extent of a foot or one hundred feet, and how long it would take for the river to lower the whole country to the sea level. Such calculations may be curious and interesting, but they do not get us very far. Indeed, we can not be sure that such calculations, if projected back into the past, would even give us a glimmer of an idea of how long it has taken to lower the valley of such a river to its present level. *Too many factors in our calculus must necessarily be neglected because wholly unknown.* If, when the river began its work, the surface of the land was all *bare* of vegetation, if the materials on which the streams worked were all *soft and freshly laid,* or if the pre-

cipitation at that time was much *greater* than it is at present, the erosive power of the rivers and surface streams would be so much greater than at present as to be wholly beyond our power to estimate.

Aggrading and Degrading Streams. When a river or stream is so overloaded with sedimentary materials that it can not well carry them all along, it must deposit some of these materials whenever for any reason the current is obstructed and its

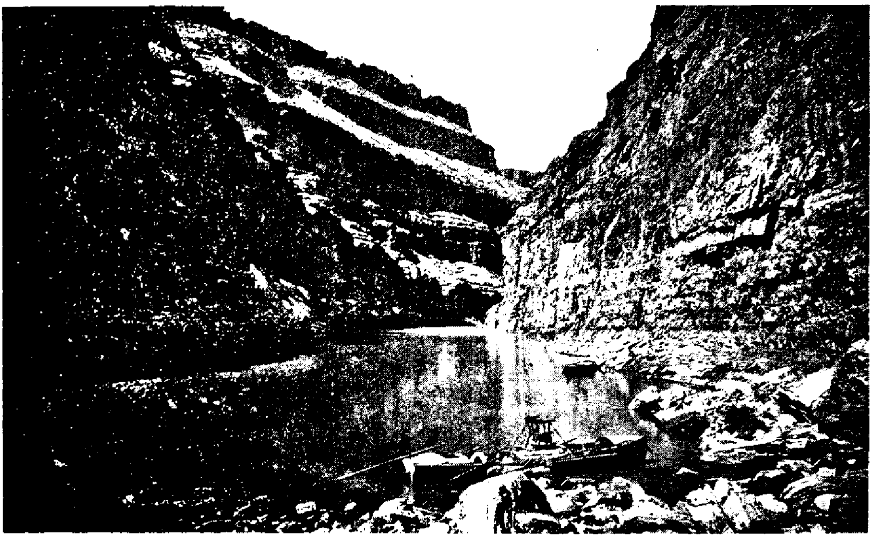

FIG. 79. The Grand Cañon of the Colorado, from the river bed. (Hillers, U. S. G. S.)

velocity is decreased. A river is said to be *graded,* or *at grade,* when its load and its transporting power are equal. It is an *aggrading* stream when it has more of a load than it can carry (Fig. 77). Or it is a *degrading* stream when it is running rapidly and could carry more of a load of sediment than it has. A river may often be aggrading or building up the lower part of its channel while it is still degrading its upper course. Thus the Missouri in its upper waters is still eroding its channel; but in the lower part of its course, it is much overloaded and is aggrading its bed.

"Young" and "Old" Valleys. It is usually assumed that a river has started its work of erosion on a level country, gradually sawing down a channel for itself through the sedimentary beds. Under normal conditions, the sides of such a channel will be worn away simultaneously with the deepening of the channel; and thus the profile which a valley displays may be

regarded as depending upon the relative balance between these two agencies, the sawlike cutting of the river and the broadening of its valley at the top. In the common language of physical geography, a valley with steeply sloping sides is regarded as *"young,"* or *"immature"*; while a valley with gently rounded or sloping sides is spoken of as *"old,"* or *"mature."* Such a use of terms is, however, very misleading, for it takes no account of the differences in the kinds of rock which a river may encounter in various parts of its course; for in one place, it may show an open valley with well-rounded sides, while in another

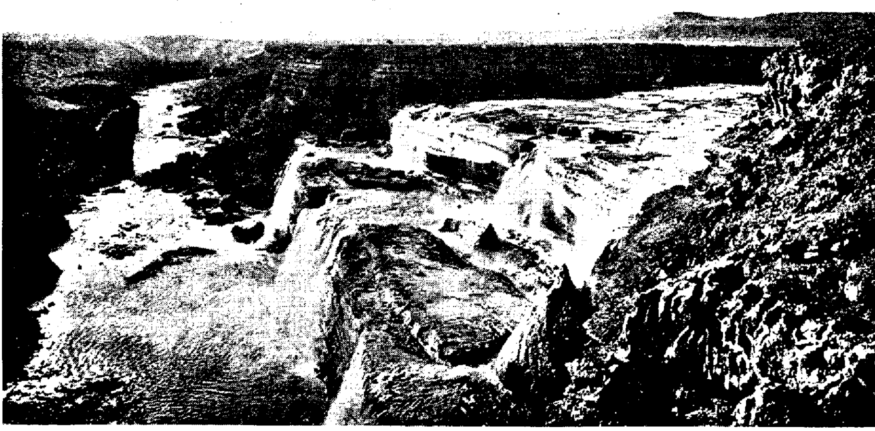

FIG. 80. Looking down the cañon of the Little Colorado River, from above Grand Falls, Arizona. (Mendenhall, U. S. G. S.)

place, it may pass through a narrow defile with steep, rocky walls, though the stream may have been flowing *through both these places exactly the same length of time.* In fact, we should remember always in this connection, as a highly respected authority has stated it, that in the use of these terms, *young* and *mature,* "absolute age is not at all referred to; they are merely expressions to denote *relative stages of development of topographic form* in a river valley during its history." (Pirsson.)

Gorges. It used to be thought that such gorges as that of the Arkansas, the Grand Cañon of the Colorado, or that of the Snake River, and the valley of the Virgin River, are examples of what ordinary river erosion will accomplish after long

ages of operation. Such calculations always assume, also, that these rivers had begun their work of sawing out their channels after all of the rocks had been *consolidated* as they are at present. But it is now quite generally agreed, or at least it is understood by many, that some of the most striking examples of this sort are merely instances of rivers which have cleaned out *a gorge or fissure already existing in the strata.* The amount of time required to effect the present condition of affairs in these instances would also be very materially reduced, if we suppose it possible that these rivers may have begun their

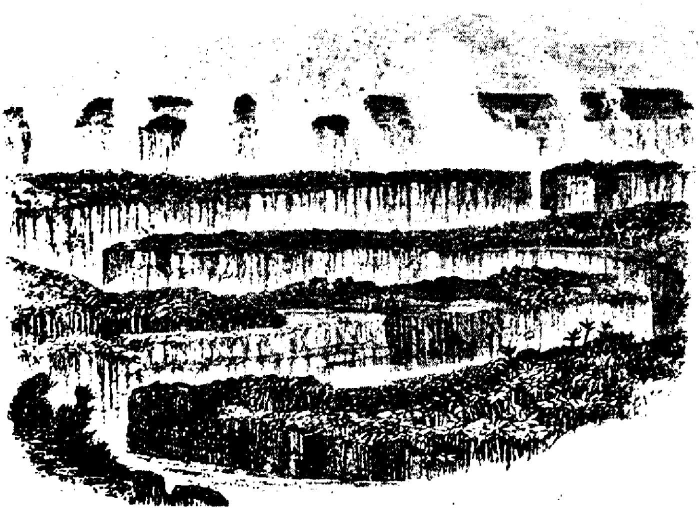

FIG. 81. Bird's-eye view of the Victoria Falls, Zambesi River, South Africa. Surely the erosive power of running water never formed such a zigzag channel as this. (After John Murray.)

work upon a mass of strata which were still soft and freshly deposited. It should also be remembered that such rivers as the Colorado are now carrying a very large load of sediment, and that they thus have plenty of tools with which to scour out the bottoms of their channels. The word *Colorado* means *red,* and is quite descriptive of the appearance of the water of this mighty stream; and there is no doubt that such a river is quite capable of digging out a channel for itself, though there is no reason at all for supposing that the present stream, rapid and loaded as it is, was the sole cause for the erosion of that immense chasm across the plains of Arizona which has been quite irreverently called the "greatest ditch on earth."

There are many examples on record, however, of gorges hundreds of feet deep which have been cut through solid rock with only two or three hundred years of work. Lyell mentions the case of the Simeto, in Sicily, which was dammed up by a lava eruption in 1603. In a little over two centuries, it had excavated a channel from 50 to several hundred feet in depth, and in some places from 40 to 50 feet in width, although the rock through which it was cutting was hard, solid basalt. He describes also a gorge cut through a

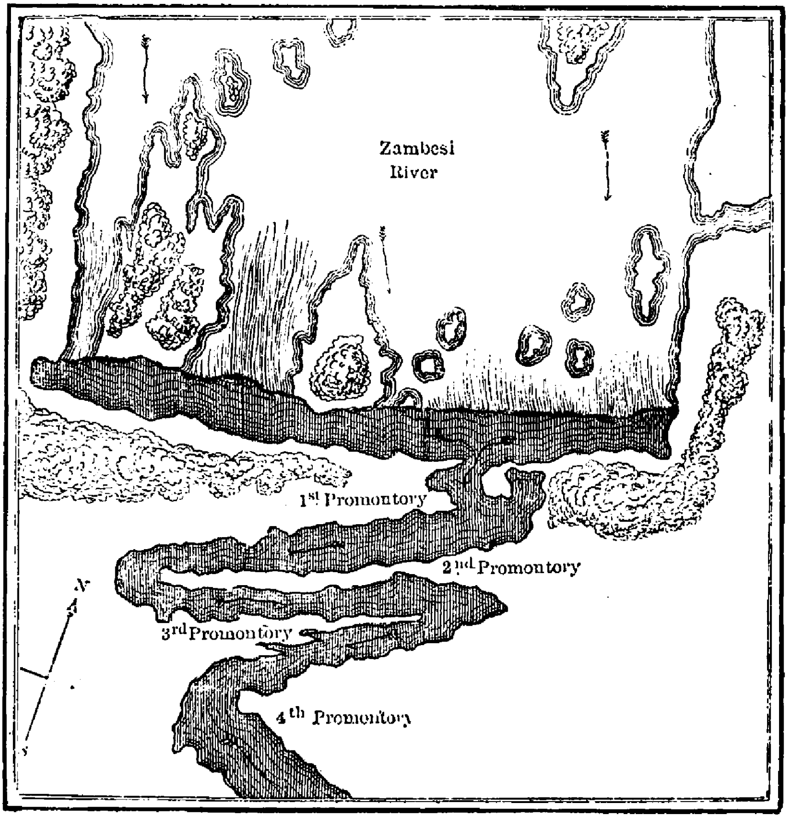

FIG. 82. Plan of the Falls of the Zambesi, Central Africa.

deep bed of decomposed rock in Georgia, which started at first as a mere mud crack a yard deep, but which in 20 years was 300 yards long, from 20 to 180 feet wide, and 55 feet deep. Another author describes a similar gorge of twice the length in Brazil, which had been made in 40 years. Like examples might be cited from all parts of the world.

In the year 1905, the Colorado River broke into the Salton Sink, in Southeastern California; and in an incredibly short time, it had cut a huge, deep trench through the soft alluvial soil (Fig. 78). This is a good illustration of what flowing water will do when acting upon unconsolidated materials. The action

of flowing water when carrying stones or bowlders may be illustrated by what happened in the Sill Tunnel, in Austria. The bottom of this tunnel or water channel was provided with a pavement or flooring of granite slabs more than a yard thick. Through this tunnel a strong current carrying great quantities of *débris* was passed at a high velocity; but so rapid was the abrasion of the granite slabs that it was found necessary to renew them after only a single year. (Scott.)

As already remarked, it seems incredible that such gorges as those of the Zambesi, in South Africa, the Via Mala, on the Rhine, or the Ausable Chasm, in the Adirondacks, were due primarily to ordinary erosion. Rather must we suppose that

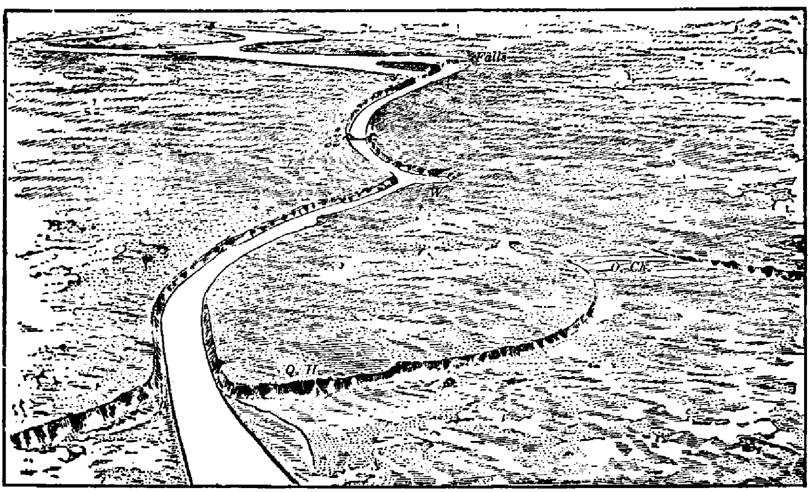

FIG. 83. Bird's-eye view of the Niagara Gorge. W., Whirlpool; Q., Queenston; Q. H., Queenston Heights; O. Ch., old channel. (From Gilbert.)

they represent chasms or fissures in the rocks through which the waters found their way and which they have since cleaned out so as to make passable channels for themselves.

Niagara. The falls of the Niagara are another classic example of a peculiar set of circumstances. Originally this river tumbled over an escarpment some 300 feet high, near Lake Ontario. Here the plateau is capped by a layer of hard limestone known as the Niagara limestone, beneath which are found a set of soft, easily eroded shales. The waters of the fall gradually undermined the limestone by eroding the soft underlying shales, thus leaving the harder limestone projecting as a ledge; and when this work of undermining had proceeded sufficiently

far, a large piece of the limestone would tumble down and be carried away. In this way, the falls have been gradually moving upstream, leaving a deep gorge behind them, until they are now some seven miles above their original position. And because there is a slight dip in the limestone upstream, the

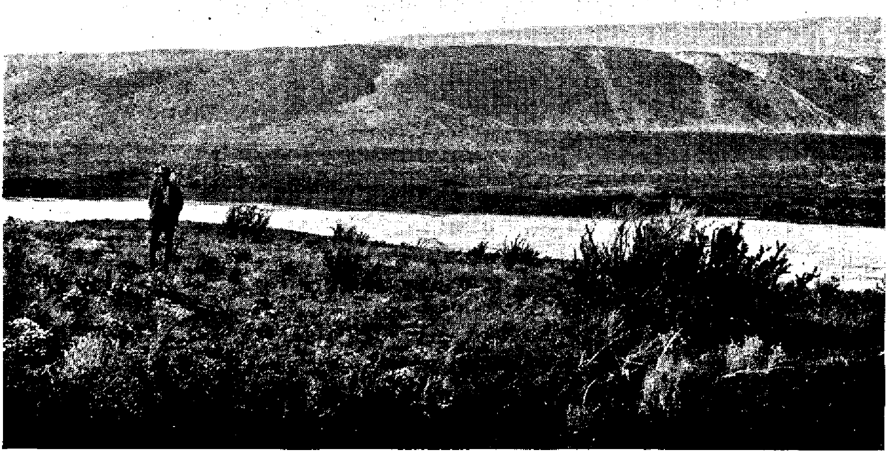

FIG. 84. North wall of Yakima River, showing old river terraces at various levels. As explained in the text, the higher terraces are of course the oldest. These terraces would be classed as Pleistocene or Recent. (Russell, U. S. G. S.)

original height of 300 feet has been lowered to the present height of about 165 feet, leaving out of account the grade in the river between the two places.

The *rate* at which the recession of Niagara Falls is now taking place has been often discussed, but it does not seem that the present rate can be accurately determined. Its present rate has been estimated at from 2 feet a year to more than twice this amount. But the falls are now nearly a mile wide, which is nearly four times as wide as they were farther down the gorge; and the present amount of water is probably much less than this stream formerly carried. Many geologists make 5 feet a year a probable average. At this rate, the length of time involved in cutting this gorge 7 miles long would be about 7,000 years. But even this amount of time would require very material reduction, if any of the factors involved were much more powerful long ago than they are now. And there is plenty of evidence in favor of the supposition that the erosion may have been much more effective long ago than it is at present.

Constructive Work. The *constructive work* of rivers is also an important part of the work which they perform. When a river carrying sediment comes to a part of its course where it spreads out much more widely than before, it always tends to drop a considerable amount of the material which it has been carrying, because its current has been slowed up. Most rivers have wide-spreading plains in the lower parts of their courses, which they overflow in flood season, such plains being known as *flood plains*. Over these flood plains, such a river constantly deposits a layer of sediment, fine or coarse, during its season of flood, this material being known as *alluvium*. The Nile is a good example of a river acting in this way, as is also the Mississippi, though the action of the latter river has been interfered with by artificial banks, or *levees*, which have been built to restrain its flood waters. As the material thus deposited by a river on its flood plain is coarser and more plentiful near the bank of the river from which the overflow has spread out sidewise, the part of the flood plain near the river is gradually built up higher than the portion of the plain farther away; and thus it happens that such a river is gradually banked in with low ridges along its course, these low ridges being called *natural levees*. Beyond these ridges, the land in generally low and swampy.

Terraces. Sometimes a river, after forming an extensive flood plain, cuts down its channel to such an extent that the re-

FIG. 85. Terraces on the Columbia River, looking down the old outlet of Lake Chelan, Washington. (Willis, U. S. G. S.)

mains of this flood plain are left high on either side as shelves or *terraces.* Important changes in the amount of materials carried by a river at different times in its history will also assist in accomplishing the same result. Often there are visible terraces at several different levels along the same stream (Fig. 84). The beds in these terraces consist of gravel, sand, or clay, generally with quite distinct stratification. In all cases where there are several terraces in a valley, one above another, *the*

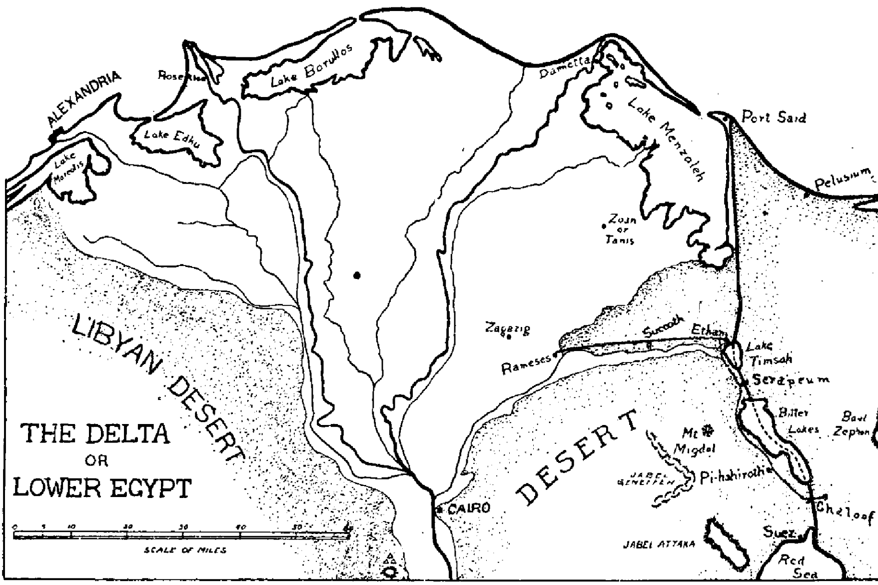

FIG. 86. Map of the delta of the Nile, showing the probable route followed by the Israelites on leaving Egypt. If the Red Sea were some 30 feet higher than at present, its water would extend up to Etham, on the north side of Lake Timsah. It is supposed that the Israelites crossed at either Serapeum or Chaloof, which would at that time be covered by some 5 to 10 feet of water, which a "strong east wind" (Ex. 14:21) might easily blow down the Gulf of Suez. (From George Frederick Wright.)

higher ones are older than the others, as already remarked, and represent the level at which the *first* sedimentary deposits were spread out. Afterwards, when the river had scooped out a much lower bed for itself, it formed a flood plain at this lower level; and perhaps after many more centuries of work, when its channel was again much lower, it may have made another flood plain, which would be not only lower but also much *narrower.* Thus a series of terraces on the sides of a valley record an interesting history of events which have taken place since the present drainage conditions became established. Yet, because of the great uncertainty regarding the many factors in-

volved, the *absolute length of time* between the formation of any two terraces is quite beyond conjecture.

Deltas. At the mouth of a river, the prolongation of the river-plain is carried out into the lake or sea into which the river empties. Often this prolongation of the river-plain is shaped more or less like a triangle, with its apex upstream, and its base forming the shore of the sea or lake. It is named from its resemblance to the Greek letter *delta.* Usually such a river discharges its waters by many channels, which are therefore called *distributaries,* each of these carrying but a fraction of the total water brought down by the river in its main channel farther upstream. Rivers which form deltas are constantly engaged in building the edge farther out into the still water into which they empty; though some rivers, like the Nile, are doing so only at a very slow rate.

Not all rivers form deltas. Usually only those entering lakes or protected seas, where the tides are weak, or at least where the tidal currents sidewise along the shore are not very strong, form deltas. Such a river as the great Hwangho of China probably brings down so much sediment that it would form a delta in spite of any tide or current. The Thames, however, has no delta, nor do any of the rivers on the Atlantic coast of Canada and the United States.

Any swift-flowing stream which carries a heavy load of sediment may form something resembling a delta as it emerges from a ravine and enters a broad plain. Such a dry-land delta is called an *alluvial cone* or *fan;* and some of them are of enormous extent. Plenty of smaller examples of such cones or fans are to be seen along the base of the hills in all arid regions, where heavy loads of material have been washed out of the narrow tributary valleys by sudden and heavy rainfalls. In examining such fans or alluvial cones, it is quite impossible to tell, in some cases, whether the major part of such a deposit may not have been formed as an actual delta, when an extensive body of water stood over the level land where we now find it. In many instances, such was probably the method of formation.

The actual depth or thickness of the deposits formed by modern deltas varies greatly, but is generally not very great. "The mud of the Nile delta is not over 10 or 15 meters thick." (Grabau.) Some of the deltas in Europe seem to be thicker than this, and that of the Ganges is about 20 meters. "The actual delta deposits of the Mississippi range from 9.5 to 16 meters near New Orleans, increasing to 30 meters at the head of the passes, beyond which the thickness rapidly increases.

They rest throughout on a stiff blue clay of earlier age." (Grabau.)

In order to agree with its theoretical structure, a delta should consist of what are termed *bottom-set*, *fore-set*, and *top-set* beds. In many of the anciently formed deltas which have since been opened up for examination by the draining of the bodies of water in which they were formed, these various beds are well displayed. But in most modern deltas, such distinctions between the variously formed beds are difficult or impossible to trace. It is also found by borings that the strata of modern deltas are generally of extremely *small area*, the borings revealing scarcely any two sections the same even in closely situated boreholes. Evidently, therefore, the beds of such a delta comprise only a *series of lenticular masses of very limited extent laterally.* In the delta region near Venice, Italy, "only two sandy layers, carrying water, have proved in any way constant; all other layers quickly wedge out laterally." (Grabau.) Often a large amount of finely divided vegetable matter is found in layers here and there in some deltas; and although such organic deposits are in no way similar to the ancient beds now forming our coal deposits, being finely comminuted and scattered through the sediments, they are sufficient to resemble somewhat the black shales so often found in ancient formations.

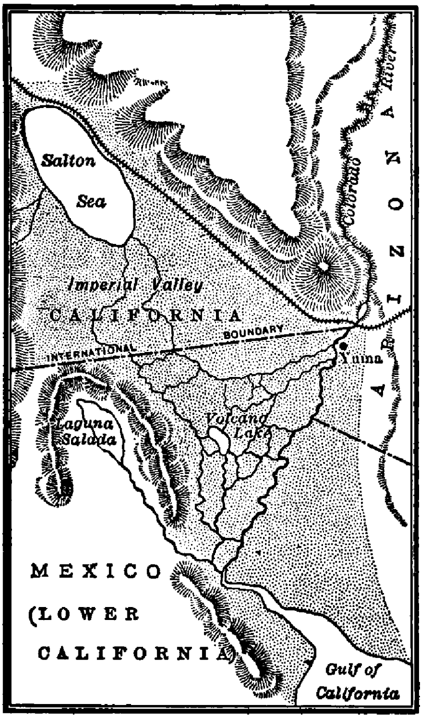

FIG. 86*a*. Map of the delta of the Colorado River, showing former distributary channels, canals, and the Salton Sea. The Imperial Valley, here shown, is now one of the garden spots of California. Its soil is doubtless composed largely of the rock materials which once filled the Grand Cañon of the Colorado.

Ground Water. Much of the water which falls on the earth's surface, whether on hill or in valley, sinks through the ground by means of the pores of the rocks or through other openings, and thus becomes subterranean or *ground water*. These waters sink down readily through the sandstones, but are stopped by a layer of clay or other compact stratum which is impervious

to water. Down below the sea level also, these underground waters usually accumulate and lie still, often being quite salty, perhaps indicating that at one time the sea water had access to these regions, or that these rocks were originally deposited in sea water, or perhaps they may have become salty through contact with beds of rock salt.

Ordinary *surface waters* easily erode limestone, because they contain carbon dioxide in solution. Following along joints and cracks in the rocks, they soon hollow out large cavities for themselves; and by this means, a complete system of underground drainage may become established. Large caverns of this character are found in all limestone regions, also in some other kinds of rock, these caverns sometimes containing large streams of flowing water.

The level at which the ground water stands, called the *water table,* depends partly upon the amount of precipitation upon the surface, and also upon the shape of the surface, being higher on the high level plateaus, and sloping away toward the valleys almost as does the surface of the ground. Yet the surface features alone do not reveal the depth at which the water level will be found.

"In a large number of very deep mining shafts in various parts of the world, and in both humid and arid regions, water is found only in the upper levels, within 2,500 feet or less of the surface, while below the mines *are dry, even dusty."— Scott, "Introduction," p. 125.*

Estuaries. Many rivers enter the ocean by a large opening which is termed an *estuary.* The mouth of the St. Lawrence is a large estuary; but many smaller ones abound along the Atlantic coast, such as those of the Hudson, Delaware, and Chesapeake. On account of the large size of these river mouths, the river water is unable to fill them entirely to the exclusion of the ocean water; hence with a mingling of river water and ocean water, the water in these estuaries is *brackish,* and is not favorable for many kinds of water animals. Many animals live in the salt water, and many also in the fresh water; but not many can stand to have the water brackish.

The deposits made in estuaries are much like those made in the sea, except that finer muds occur in the estuary at any given depth of the water. Sands and gravels occur on exposed situations, though the rivers do not bring down any coarse materials so nearly into the sea. All kinds of stratified deposits in estuaries are likely to show a *confusion of stratification,* due to the conflicting currents and eddies in which they were laid

down. But there is really no well-marked difference between the deposits in an estuary and those formed elsewhere along the coast.

As might be expected, no great variety of either marine or fresh-water fossils can accumulate in estuarine deposits. Animals from either the salt or the fresh water may be killed by getting into the brackish water of the estuary; but as a rule, such animals are never buried in these situations. Vertebrate

FIG. 87. When water gets in a hurry, it can carry masses and perform work wholly incommensurable with its effects under normal circumstances. The effects of a flood, August, 1901. (U. S. G. S.)

fish are more likely to be killed in this way than are any other forms of life; and such fish will always float to the surface in a short time, and before very long will be devoured by other forms of life. *Practically none of them will ever be buried in the muds and sands of the estuary, or, indeed, be buried anywhere else.* The custom of many writers on geology of classing as estuarine deposits any set of beds which happen to contain a mixture of both marine life and forms from the lands or from fresh water, is much to be deplored, for it is merely an evasion of the evidence which such deposits present.

Abrading Action of Sediments. Water that carries no sediment has no wearing or abrading effect when flowing over a

smooth surface. But when thrown in masses against any flat surface, as in plunging waves or torrents, it may be the cause of very marked results. Immense blocks of stone, weighing perhaps many tons, may thus be moved slightly at each impact of the water, and in the course of time transported over considerable distances along a level or slightly sloping surface.

When loose material, such as sand or gravel, is carried by moving water, this material is made to act like the emery of an emery wheel, but with only slight pressure. At the same time, the material thus transported is itself worn away by the pieces of sand, gravel, or stones being rubbed against each other, thus rounding them. However, it seems that after these particles reach a certain grade of fineness, they are no longer worn away by mutual impact.

CHAPTER VIII

Ice as a Geological Agent

More than half of the lands are covered with snow and ice for several months each year, and large areas are permanently covered. Hence these materials are at the present time of much geological importance; and we can not undertake to solve all the problems regarding the geological work of the past, unless we understand what ice is now doing, and learn to read the records which it leaves behind.

River Ice. *River ice* becomes important when it picks up stones from the shore and from the bottoms of streams and carries them off as the ice breaks up in the spring, to deposit them perhaps a long distance away. It is even more important from the manner in which it accumulates in the channel of flowing water and dams it up, producing lakes of greater or less extent. All the streams in the colder latitudes are thus affected every spring; and when this moving mass of river ice can dam up such a mighty river as the St. Lawrence, endangering cities like Montreal, as occurs almost every year, we can understand that river ice is an agent of no small importance. It would be of even vastly more importance if, on the hypothesis of a land surface just emerged from the ocean, the larger part of a continent were devoid of a protecting mantle of vegetation, and especially with no forest cover. A nearly level country, such as we have in Minnesota, could not fail to be fairly pock-marked with irregularities on the surface, thus producing innumerable lakes, if the conditions which we have spoken of were fulfilled.

Lake Ice. *Lake ice* has also another action which needs to be considered. When a pond or a lake is frozen over, the ice completely fits the surface of the water. With still further freezing, the ice undergoes contraction, resulting in huge cracks or fissures in the ice, the size of these fissures — that is, their width as well as their length — depending upon the size of the body of water which is frozen over; in large lakes, they may be several feet wide. But as the water rises and fills these cracks, it also is frozen solid, completely restoring the surface cover of the water, so that the ice again completely coincides with the extent of the water surface, this ice being now perhaps many degrees below the freezing point.

But when the temperature again rises, and the ice nears the melting point, the whole surface of the lake must *expand.* And the actual amount of this expansion will be proportional to the size of the body of water affected. In a large lake, it may result in pushing the edge of the ice violently against the bank or the shore of the river or lake, forming what are called *ice ramparts,* which are heterogeneous masses of earth and stones indistinguishable from masses of rocks piled up from other causes, except in so far as the proximity of a large river or lake may give the key to their origin.

Above the Snow Line. On the high lands of all the continents, there are regions where the ice and snow never melt, but where masses of frozen water keep accumulating from year to year, forming permanent ice fields or snow fields. In warm latitudes, this can occur only on the tops of the highest mountains; in more northern latitudes, these permanent accumulations of snow and ice are much lower; while in the arctic regions, permanent ice and snow are about at sea level. In any particular locality, the point of elevation at which snow remains over the summer without melting is called the *snow line.*

FIG. 88. Deposits made partly by stranded ice; on the west coast of Greenland. (Photograph by Libbey.)

In the tropics, the snow line is between 15,000 feet and 18,000 feet high; in the Alps, it is about 9,000 feet; and in Norway, about 5,000 feet. Much depends upon the amount of annual precipitation; the snow line is very much lower in regions of heavy precipitation than in regions where the total rainfall is light and where there is much evaporation, it being nearly half a mile higher on the dry western side of the Andes than on the moister eastern side. Montana, with its dry climate, has a much higher snow line than Switzerland, which is in about the same latitude.

The weight of the accumulating mass of snow above the snow line in suitable places, presses the flakes together until the mass assumes a very distinctly granular structure, much like the snow which remains for a long time in the spring as

FIG. 89. View showing the terminus of the Mer de Glace Glacier, Chamonix Valley, Switzerland; also showing the terminal and lateral moraines about the lower end of the glacier, evidently formed long ago, when the glacier was much larger than at present. (Holmes, U. S. G. S.)

the relics of large drifts, as we see it over all the north temperate lands. This granular ice is termed *névé* — the French word used by the mountaineers of Switzerland.

Glaciers. The mass of granular ice accumulates to a great thickness in the valleys and amphitheaters among the peaks; and at some outlet on the lower side, we can detect a movement downward, much as if the ice were a thick, viscous, semiliquid mass, this point where movement downward begins being the beginning of a *glacier*. A glacier may be likened to a river of

ice; it derives its energy of movement *entirely from its gravitation.* As a geological agent, it works by falling; and it works as long as it falls, but no longer; and the amount of work it can do depends upon this falling movement, which is caused wholly by gravity.

At the lower end of the glacier, where the ice foot is being pushed out into a comparatively warm region much *below the snow line,* there necessarily come a time and place where the ice must melt faster than it can advance; and this means the end of the glacier. It has been compared to a rod of ice thrust into a furnace; the distance such a rod could be thrust in before being melted would depend upon its size, the rate at which it was pushed in, and the heat of the furnace. Accordingly, in warm tropical regions, we should not expect glaciers to extend much below the snow line; and they do not. But in northern countries, they often extend *far below the limits of the snow line;* and in the far north and south, we find them pushing down to the very ocean itself, where the foot breaks off in huge pieces and forms *icebergs,* the latter being sometimes miles in length.

In the Alps, some of the larger glaciers extend 5,000 feet below the snow line. In the southern part of New Zealand, they extend down to levels where subtropical forests, including tree ferns, grow side by side with the foot of the ice mass; while

Fig. 90. View in Glacier National Park, Montana. General view of Grinnell Glacier, Gem Glacier, and the Garden Wall, from the slope north of Grinnell Lake. (Stanton, U. S. G. S.)

FIG. 91. A large hot rock which was washed by a flood five miles from the crater of Mount Lassen, California. (Photograph by Loomis.)

they even descend to the sea level in the southern part of Chile, at about latitude 47° S.

The granular structure of glacier ice is not always apparent where the ice has been subjected to much pressure. But even here the structure may be clearly detected by subjecting a thin section of it to examination under polarized light. At the lower end of the glacier, also, this granular form reveals itself; for under the differential melting which the particles there undergo, the mass breaks up into pieces of what resembles sand or gravel. It has also been proved that the movement of the ice, as the glacier gradually flows down grade, is due to the shearing or slipping of each of these little crystals past or over others; so that the movement is not exactly like that of a true viscous fluid, such as cold molasses, to which it used to be often compared. Yet, like a true viscous fluid, its mass movement is wholly due to gravity.

The truth seems to be that the particles can move upon one another only as the pressure causes them to melt slightly at their points of contact, *this melting being promoted by pressure*, which counteracts the expansion all ice undergoes when it forms. At any given temperature near the melting point, the ice can be *made to melt* by a sufficient amount of pressure; but when this pressure is relieved, the ice instantly *freezes again*, since its actual temperature is below the freezing point still. Indeed, the temperature at any particular depth of the glacier seems to correspond with the melting point of the ice for the pressure at that depth. From this, it follows that *the depth of the glacier can not increase indefinitely*, about 1,600 feet being apparently the maximum. With greater thickness than this, the bottom parts would melt because of the pressure of the load.

There are some 2,000 glaciers, large and small, in the Alps, most of them being less than a mile long. Several are from three to five miles in length, while the largest, the Aletsch Glacier, is

ten miles long and about two miles wide. Glaciers occur also in Northern California, Oregon, and Washington, with many in Alaska, the Seward Glacier, near Mount St. Elias, being some fifty miles long and three miles wide at its narrowest part. This glacier unites at its foot with several others, forming the huge nearly stagnant ice field known as the Malaspina Glacier, which covers a total area of some 1,500 square miles.

The Movement of Glaciers. Greenland and the antarctic continent are covered with what are called *ice caps,* these being deep accumulations of glacier ice which move slowly outward from some high central point toward the seacoast, where great blocks of the ice break off in the form of icebergs, which are thus always formed of fresh-water ice.

In the Alps, the movement of the glaciers is from 300 feet to 1,000 feet a year, or from one to three feet a day. The Muir Glacier, in Alaska, is said to move 2,500 feet a year; while some in Greenland move much faster than even this, because of the immense mass behind, which is pushed out through narrow valleys into the sea.

The ice of a glacier does not move as fast along its margin as it does in the center of its mass. The top also moves faster than the lower layers. So there is a decided difference in the rate of the different parts. In these respects, also, it acts somewhat like a river; it is a case of a genuine flowage, much like that of a viscous fluid. From a molecular study, there is also a shearing movement of the minute parts upon one another, by little starts and stops, as might be expected of an elastico-rigid body, as we know ice is.

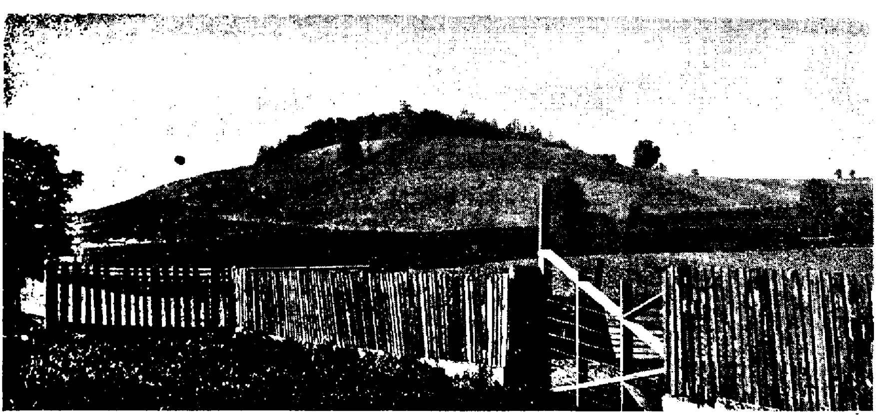

FIG. 92. North end of drumlin, one mile south of Newark, New York, looking south. (Gilbert, U. S. G. S.)

The surface of every glacier is traversed by great cracks, called *crevasses,* which run more or less transverse to the course of the glacier. They are caused by the irregularities over which the ice is moving, which produce strains and tensions which the ice can not resist. At the side and at the lower end of the glacier, we always find a mass of clay, pebbles, and even huge bowlders which have been brought down by the glacier, these piles of miscellaneous material being termed

FIG. 93. Section through a drumlin, Koshkonong quadrangle, Wisconsin. (Alden, U. S. G. S.)

moraines, the one at the foot being a *terminal* moraine, and those at the sides being *lateral* moraines. One or more rows of *débris* may be seen riding on the top of the glacier, these rows being termed *medial* moraines. In addition, there is sometimes a mass of material which is carried along by the glacier over the bottom of its channel. This is called a *ground* moraine. The terminal moraine may be piled up 25, 50, or even 100 feet high, and may constitute indeed a very imposing mass of material, which, of course, will have no stratification in it. Much of this material has been brought down by the ice mass, embedded within it, and thus has not been subjected to much wearing or grinding. Other fragments, however, have been

used as tools, being embedded in the foot of the glacier itself; and these are often striated or scratched, or even rounded and polished, through contact with the rocks of the channel through which the mass has been moving. These rocks over which the glacier has moved are seen to be more or less smoothed and scratched, a neat channel having usually been made by the ice river for itself. As the result of this wearing of the rocks,

FIG. 94. Esker, Westford Township, Dodge County, Wisconsin. (Alden, U. S. G. S.)

the water which issues from underneath the lower end of the glacier is always of a peculiar milky appearance, due to the rock flour with which it is loaded.

Most of the modern glaciers seem to be gradually getting smaller, the lower ends not pushing down so far as formerly. In some instances, this has been questioned; but it seems that so far as we can determine, the glaciers were much larger a few hundred years ago than they are at present. At any rate, at some time in the long past, glaciers of much greater magnitude than any now existing were at work in the Alps, in Scandinavia, in the Rockies, and practically everywhere over the world where there are glaciers at present.

The So-Called "Glacial" Phenomena. Some of the phenomena which continental glaciers are invoked to explain, and

FIG. 95. Section of an esker, showing oblique bedding, manifestly formed by flowing water. 9½ miles north of Menominee, Michigan. (Russell, U. S. G. S.)

which they do not always explain very satisfactorily, should be mentioned.

1. *Drumlins.* These are oval-shaped or elliptical mounds of heterogeneous materials, though often stratified, which are found scattered over wide areas of the so-called "glaciated" parts of America and Europe. They look like hillocks which have been nearly worn away by erosion; and if they were situated in the plains region of America, where erosion has been relatively feeble, they might be mistaken for buttes. They usually have their axes pointing in the direction of the larger drainage of the country where they are found.

2. *Kames.* These are short ridges or hillocks of distinctly stratified gravel and sand, which were evidently made by water, in some manner not well understood. They often seem to be crosswise of the general drainage.

3. *Eskers.* Long winding ridges of gravel, often strongly resembling an old abandoned road or railway embankment, sometimes 20 or even 100 feet wide, are found running for

long distances, sometimes for many miles, as in Scandinavia. They are very common in Maine.

4. *Crag-and-Tail Phenomena.* A very common thing is to find an outcrop of hard crystalline rock facing in a direction which is upward, so far as the general drainage of the country is concerned, with a wide stretch of till spread out behind it, strongly resembling what is found in many streams. The difficulty in these cases, however, is that, in order to have water flowing where we find these phenomena, the whole country would almost have to be flooded; for in many cases, they are found near the crest of the country, where no running water has existed, apparently, since the present topography of the country was established.

5. *Potholes, or Kettles.* Great holes, sometimes 100 feet deep, perhaps filled with water, are often found here and there over these areas.

6. *Perched Bowlders.* Great pieces of rock are often found in such peculiar situations that one wonders how they could have been placed there by either water or ice. It may almost be said that these huge blocks of rock are very frequently found on points higher than the general trend of the surrounding country. Traveled bowlders are a very common phenomenon over all the region which we are discussing. Many of them are as large as a small house; and some of them, both in this country and in Europe, have become so individually famous as

FIG. 96. An esker which is transverse to the trend of the neighboring drumlins, one half mile north of Spalding, Menominee County, Michigan. Looking east. (Russell, U. S. G. S.)

to have received distinctive names, like those of a mountain or a river or a lake.

These are a few of the phenomena which glaciers are called upon to explain; but the ordinary things for which this theory was invented are the great stretches of transported materials, different from the country rock beneath, and hence *not residual materials*, which are found spread out over many wide stretches of the areas here spoken of. Glaciers are supposed to explain

Fig. 97. Perched bowlder of granite porphyry, on a ledge of Cambrian sandstone, "Driftless Area," Wisconsin. (Alden, U. S. G. S.)

all the scratches (*striæ* and groovings and flutings) in the rock surfaces; and particularly the rounded, hummocky rocks *(roches moutonnées)* found within the areas of many of these "glaciated" districts.

Objections. Some objections which have been urged against the theory of a continental glaciation, such as has been postulated by the evolutionary geologists, are as follows:

1. The impossibility of ice masses' being *thick enough* to cover the high points where the "glacial" marks are found. These marks are found on the very tops of the highest mountains in New England and New York. In the Green Mountains, they are found at a height of 4,400 feet; and in the White

Mountains, 5,500 feet high. Yet the physicists declare that ice can not be piled up higher than 1,600 feet without the bottom layers' starting in to melt because of the pressure of the incumbent mass. The thickest ice known on earth to-day, which is in the antarctic region, is not thicker than this maximum; and according to the laws of physics, the ice could never get thicker than this amount.

2. The same principle appears in another form, when we try to imagine ice flowing out from two or three centers over the

FIG. 98. "Glacial" (?) striæ, on Permian rocks, Riverton, Vaal River, South Africa. (R. B. Young.) Evidently something besides continental glaciers must have produced these striæ.

larger part of North America; for in order to have the ice pushed even a fraction of the distances which this theory requires, an amount of *pressure* would have to be exerted *behind* the mass (presumably by gravity) which would far exceed the amount represented by a vertical column of 1,600 feet. Hence it is hard to see how the ice could have traveled across the country in the way it is said to have gone,— down to the Missouri and the Ohio, with centers over Labrador and Keewatin.

3. The so-called glaciated areas are *peculiarly distributed.* Alaska is not affected; neither is Siberia, nor much of Russia. Also there are even "driftless" areas within the limits of the

supposed glaciers, one of the largest and best-known being in Wisconsin.

4. The many evidences of *semitropical conditions* over much of these regions, as presented by the fossil plants and animals which are found in these so-called "glacial" deposits.

5. The *marine fossils* often found interstratified with the "glacial" beds.

That glaciers are very efficient agents of erosion and of transportation on a small scale, can not be doubted. That they can scratch up their channels, transport immense blocks of rock for miles, and pile up a heterogeneous mass of *débris* at their lower ends, are all matters of observation. But that in the long ago immense ice caps covered the greater portion of the northeastern part of North America and the northwestern part of Europe, is mere matter of speculation. This is not the place to give the beginning student a long controversial discussion of this much-mooted question; but the few facts just given will serve to show that the extreme doctrines regarding former glacier action are not beyond criticism.

These subjects will be further discussed in a subsequent chapter, where the consideration of these theoretical questions more naturally belongs.

CHAPTER IX

The Ocean and Its Work

Destructive Work of the Waves. The ocean is by far the most important agent of geological work, and "rocks of marine origin form the larger part of the present land surfaces." (W. B. Scott.) The work now being done by the ocean may be considered under the two general heads: the *destructive* work, performed chiefly by the waves of the shore; and the *constructive* work, or the laying down of deposits in the ocean, which takes place mostly far from the shore.

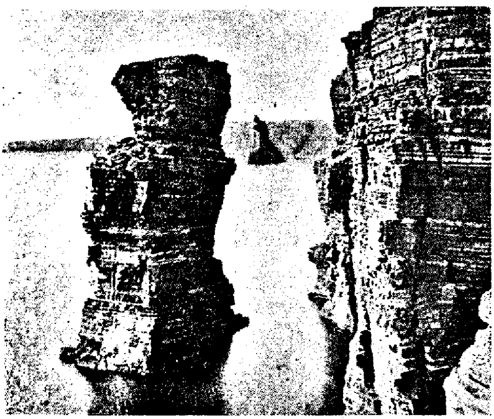

FIG. 99. Wave erosion in nearly horizontal strata, Duncansbay Head, Orkney Islands, Scotland. (From W. B. Scott, "Introduction to Geology," permission of Macmillan Co.)

The ocean waters accomplish their destructive work principally by means of the *waves* which are propelled by the winds blowing over their surface, and by the *tidal currents* which are generated by the attractive force of the moon and sun. The ocean currents, though very important in modifying the climates of various localities, are usually so shallow in their extent, they are so far from shore, and flow generally on the surface of such deep water, that they have little or no mechanical effect upon the materials at the bottom. Possibly the Gulf Stream may keep its narrow channel cleaned out as it passes through the Florida Straits, but this is a very unusual thing for an ocean current to do.

As the result of friction and of unequal pressures on the surface of the water by the wind, the upper waters of the ocean are readily put in motion in a series of oscillations up and down. Normally this action of the waves is merely an up-and-down motion or oscillation, and does not carry the surface water forward, though the friction of the wind does propel the mere surface layers to a slight extent. However,

when a wave nears the beach and strikes shallow water, it changes its character; for as the rising and falling masses of water encounter the bottom, part of their mass is forced by the hydrostatic pressure of the wave to rush forward as a *breaker,* the top of the wave also occasionally curling over and adding to the momentum of the forward-rushing mass, which thus becomes a powerful force in the way of geological work. These breakers are a constant factor, working away day and night, "without haste, without rest," along all the coasts of the world. Under the propulsion of violent winds, these wind-waves may have all the force of a thousand battering-rams, accomplishing results that are almost incredible.

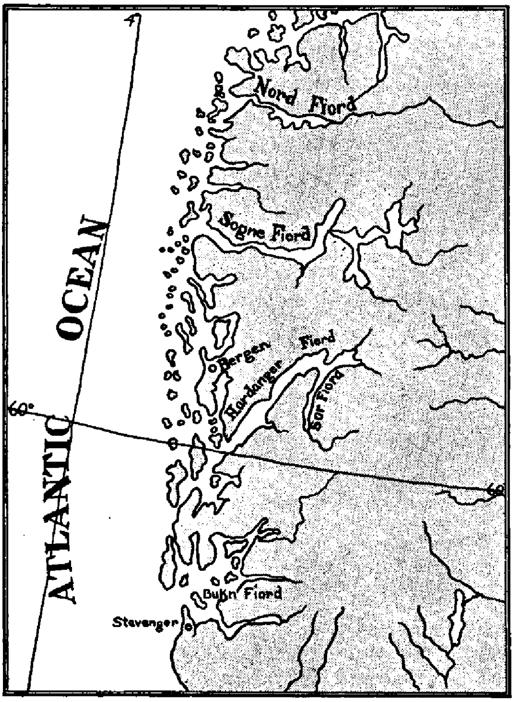

FIG. 99*a*. Map of a part of the west coast of Norway, which is a characteristic "weather coast." Here the currents and winds are prevailingly on-shore, with the result that the sedimentary materials have been almost entirely carried away, leaving bare the old, hard crystalline, or Archæan rocks. Such a coast has often been termed a "submerged" coast; but there is no real evidence of its gradual submergence.

Some lighthouses in exposed situations are kept almost continuously covered with sprays, even from ground swells when there is no wind, these sprays being thrown perhaps to the height of 100 feet, which would represent a pressure causing it of nearly 3 tons to the square foot. Since a cubic foot of water weighs about 64 pounds, the mere hydrostatic pressure of a wave 20 feet high would be 1,280 pounds, or over half a ton, to the square foot; the rest of its force coming from its momentum. According to observations made on the coast of Scotland, the average wave pressure there for the summer months was 611 pounds to the square foot, while for the six winter months the average was 2,086 pounds. Even these figures are greatly exceeded in violent storms, when the force of the breakers is often many tons to the square foot.

Dana records some remarkable driftings of beach materials along the Atlantic coast. "A vessel, the *Sylph,* was wrecked in 1814-1815 on the south coast of Long Island, and the ma-

terials from the wreck drifted westward beyond Fire Island; and 7 years afterward her rudder [a heavy thing that could not float] was found 20 miles west of where she was lost. In another case, coal from the cargo of a vessel wrecked on the south side of Nantucket was carried eastward and then northward, and the keeper of the lighthouse of the north cape, called Grand Point, supplied himself from it with fuel for the winter; and brick from another vessel pursued the same course. Again, an anchor with 10 fathoms of chain attached, from a brig of 200 tons wrecked on Cape Cod near Truro, was drifted a mile and a half to the north in three weeks. . . . Such transportation is beyond the power of any currents; it is the work of the dashing, lifting, and propelling waves."

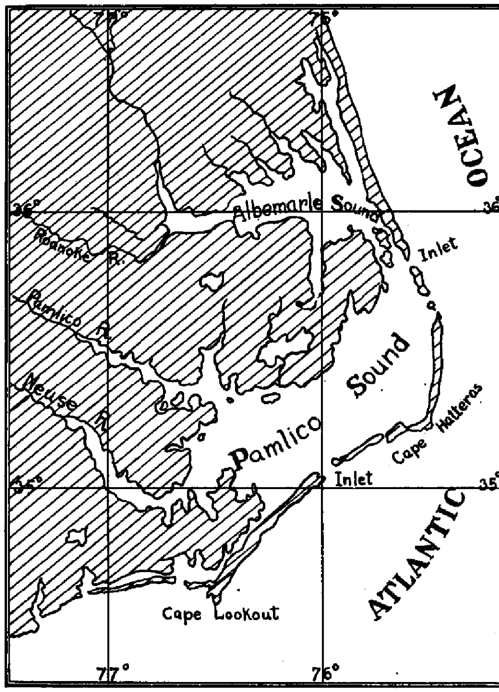

FIG. 99b. Map of the North Carolina coast, illustrating the characteristic features of a "lee coast," with its barrier beaches and inclosed sounds. Here the prevailing winds and currents are off-shore, resulting in the constant accumulation of materials. It is not an "emerging coast," but a sheltered coast, a "lee coast."

The power of the waves to lift and transport rocks of enormous magnitude may be illustrated by what happened to the breakwater in the harbor of Wick, on the northeast coast of Scotland. "This breakwater consisted, above the foundation, of three large blocks, weighing 80 to 100 tons each, across which a huge concrete monolith, weighing over 800 tons, was cast in place and firmly anchored to the blocks by iron chains. The total mass weighed 1,350 tons; and yet during the great storm of December, 1872, it was lifted by the waves and hurled into the inner harbor, a distance of 10 to 15 meters, the monolith and three foundation stones remaining anchored together and being moved as a single mass." (Grabau, "Textbook of Geology," Part 1, p. 428.)

There seems to be some uncertainty as to the depth at which the waves may affect the material lying on the bottom. The size of the waves has much to do with this depth, and from this it follows that the depth of this wave influence is much greater in the open ocean and in large seas like the Mediterranean than in smaller seas or inclosed lakes. "Probably 600 feet represents the limit at which fine sand is disturbed off the Atlantic coast, but at from 60 to 100 feet sand, gravel, and even pebbles are moved." (Pirsson, "Textbook of Geology," p. 97.)

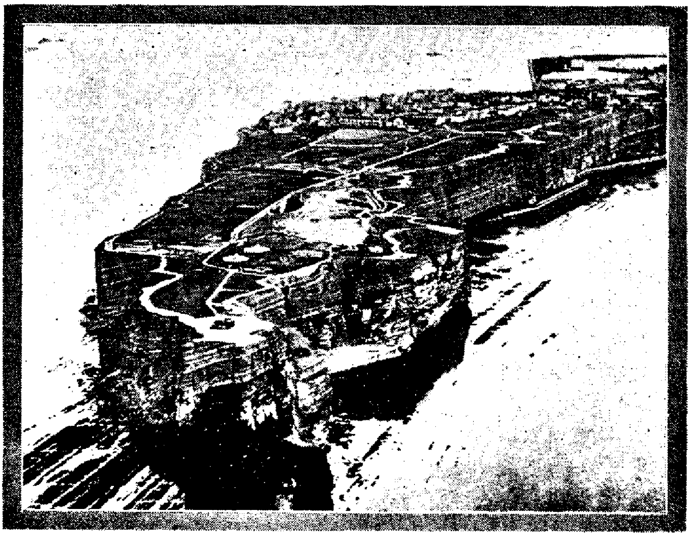

FIG. 100. The island of Helgoland, North Sea. In the year 800 A. D., this island had an area of 120 square miles. At present, it is only one third of a square mile in area.

Their Action on Weather Coasts. The results accomplished by the waves on the coast will depend largely upon the character of the coast itself. If the coast is high and rocky, and composed of hard crystalline rocks with few and inconspicuous joints, the results of wave erosion will be insignificant compared with their work on a coast where the shore is composed of nearly horizontal stratified beds that are only slightly consolidated. In the latter instance, the sea often keeps eating steadily into the mainland with a most alarming persistence and regularity, and towns that once were many miles from the shore have been abandoned and finally engulfed by the insatiable waters (Fig. 99). The sea accomplishes such a result by picking up the materials of the cliffs which it has undermined, and hurling these materials as projectiles against the base of the cliffs which still remain. In storms, huge masses

weighing many tons may thus be flung against the base of the cliffs, still further undermining them; and when the tops of these tumble down, they are in turn converted into the weapons of the storm and thrown against the parts of the shore which are still standing.

On the coast of Yorkshire, in England, the sea is advancing at the steady rate of about 7 feet a year. The island of Helgoland (Fig. 100), off the mouth of the Elbe, in the North Sea, is at present only about a mile long and a third of a mile wide; but in 800 A. D., it had an area of 120 square miles, being reduced in 1300 to 45 square miles, and in 1649 to 4 square miles. It would doubtless have entirely disappeared long ere this, if its shores had not been artificially protected by elaborate stone structures. Most of the shores surrounding the North Sea seem to be in process of destruction by the encroaching waters.

On sandy coasts, the waters often work with much less effectiveness, sometimes even accumulating materials instead of carrying them away. In cases where the sea is advancing, the surf can cut back the shore only at a *constantly decreasing rate;* because as the waves cut away at the shore, they leave the

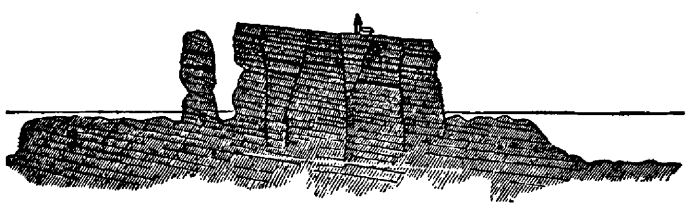

FIG. 101. Diagrammatic view of the island of Helgoland (direction S. W. by N. E.), showing the wide erosion platform on the S. W. side, where the dip is toward the island. The rock is Bunter sandstein (Triassic). (After Walther.)

materials thus made in the form of a shelf covered with shallow water, and such shallow water greatly diminishes the force of the waves by friction, so that the waves work with constantly diminishing force. "Just how far such a coast may be cut back is not definitely known, but it probably does not exceed a few miles at most." (Scott.) The only way in which the ocean could be capable of planing down a continent to the sea level, would be by the land's conveniently *subsiding* as fast as the waves were inconvenienced by the waste products of their erosive work. As to whether or not the coasts in any localities are now undergoing progressive subsidence, we shall see later. But if such a subsidence should occur at about the same rate as

the sea was advancing, it is evident that the entire surface of the land thus affected would progressively *go through all the experiences of a beach*, with no materials that had not thus gone through the great mill of the grinding and pulverizing waves.

On the other hand, coasts which are composed of hard crystalline rocks with little jointing, seem to be almost proof against the most violent attacks of the ocean. The extreme eastern coast of the United States, with that of New Brunswick and

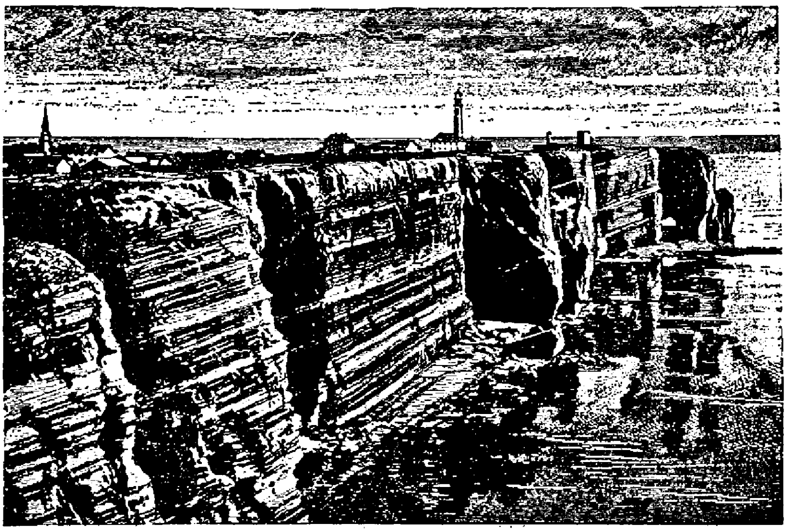

FIG. 102. Sea cliff on the south shore of Helgoland, showing how the stratified rocks have been worn away by the ceaselessly acting waves. The rocks are Permian. They appear to be horizontal, from this point of view, but in reality they dip slightly to the north. (After Walther, Haase, and Grabau.)

Nova Scotia around the Bay of Fundy, would seem to be about as violently assaulted by both wind and tidal currents as any part of the world; yet the rocks along the shore in most parts of this area are not perceptibly being worn away at all. Usually the waters near the shore are clear and free from rock fragments, and the complete harmlessness of the waves is often seen by the fact that the rocks are covered with seaweeds down below the level of low tide, which could not be the case if these rocks were undergoing erosion. Yet the tide rushes along these shores four times each day, often at the rate of ten miles an hour, or the rate of a rapidly flowing river.

The Tides. Twice each day, a bodily movement of the whole mass of the ocean takes place, due to the attraction of the moon and the sun. As this movement is dependent upon

the earth's eastward rotation, it moves westward at the same rate as the earth's rotation, or 1,000 miles an hour at the equator. The height of the actual movement in mid-ocean is quite insignificant, being calculated at less than an inch. (G. H. Darwin.) But shelving shores and bays increase greatly the magnitude of the movement, and proportionately its efficiency as a geological agent; for under these circumstances, it becomes a *translation wave,* with almost incredible power as a transport-

FIG. 103. A curving beach. Conception Bay, Newfoundland. If a coast were to subside gradually for a long period of time, every part of it would have to pass through the stage of a beach line before it became an ocean bottom. (Walcott, U. S. G. S.)

ing and denuding agent, its transporting ability increasing as the sixth power of its velocity, just as in the case of running water, a subject which has already been discussed.

However, it should be noted here that while ordinary waves due to the action of the winds are extremely superficial in their action, being limited to a few feet in depth of the surface water, the tidal wave *theoretically* extends to the very lowest depths, and is a bodily movement of the ocean to its very bottom. Yet, in the open ocean, and, indeed, on all but shelving coasts and in peculiarly shaped channels, it has little or no eroding effects. That it has little or no effects on the bottom of the ocean is proved by the fact that the softest oozes lie on the bottom of the ocean absolutely unaffected by it.

The reason for this latter fact seems to be that in the open ocean, the tidal action is merely an up-and-down movement, and this of only very slight extent; but on soundings, and especially where converging coasts tend to bring a wide stretch of waters to a focus, the tidal wave, as already remarked, becomes a translation wave, which is a *bodily movement forward* of the water. The outflowing current, or the *ebb,* from bays and estuaries has some noticeable effect in scouring out confined channels, producing some of

the so-called "drowned" estuaries; but in general, it is the incoming tidal wave, and not the current, which does the work accomplished by tidal waters.

Translation Waves. Scott Russell was the first to analyze the normal action of rapidly flowing water, and the first to discriminate between the mere undulatory movement of ordinary waves and the bodily movement of a wave forward from one position to another. The latter he called a primary wave of *translation.* It differs entirely from other waves in its origin, its behavior, and the laws governing its action. "By its transit the particles of the fluid are actually raised from their places, transferred forwards in the direction of the motion of the wave, and permanently deposited at rest in a new position at a considerable distance from their original position. There is no retrogression, no oscillation; the motion is all in the same direction, and the extent of the transference is equal throughout the whole length." (Howorth.)

This principle of a movement of the water forward in the form of translation waves is a very important one; for very probably much of the ancient geological work, as recorded in the fossiliferous strata of the long ago, was accomplished in some such manner.

Ocean Currents. The surface of the ocean is in constant though mostly slow motion. In the tropics, its general movement, called drifts or currents, is westward, probably due in large measure to the friction of the trade winds. At least the ocean currents follow the trade winds as to direction, as a general thing. When a current reaches the edge of a continent at the west side of an ocean, it is *deflected poleward,*— northward in the Northern Hemisphere, and southward in the Southern. This is in accord with Ferrel's law, which we have already studied in connection with the winds. When a poleward current reaches a latitude of about 35° or 40°, the flow diverges more and more from the continent, and circles around to the eastern border of the ocean, unless some land happens to intervene and deflect it from its course. In such a case, it may keep to the northward, like the Gulf Stream, which continues on past Great Britain and even past Iceland into the polar seas, with profound climatic effects.

Currents are always made in the waters of the ocean, and even in large lakes, by any long-continued winds in one direction. The trade winds of the tropics thus become the primary propelling power of the ocean currents. The rotation of the earth eastward is responsible for the *direction* which they take on leaving the equatorial regions; because when any body is

moving from the equator toward the pole, its rate of eastward rotation is constantly decreasing. "Flowing waters in the Northern Hemisphere, whether of rivers or of the ocean, and whatever their source, are thrown toward the right side as they advance, and in the Southern Hemisphere toward the left side." (Dana.) This is a formal statement of *Ferrel's law*.

In illustration of this law, we have the Labrador or polar Atlantic current lagging behind the rotation of the part of the earth to which it is flowing, thus keeping to the right, or the

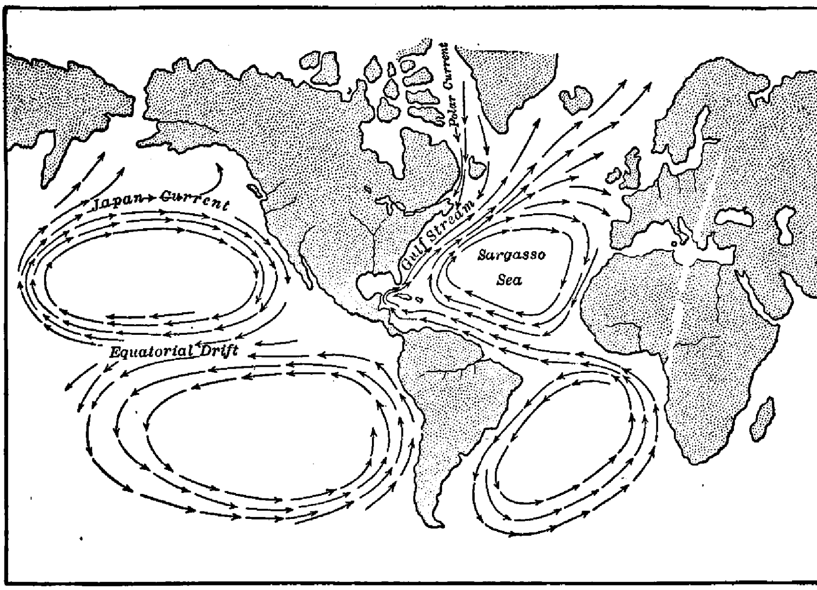

FIG. 104. Diagram of the ocean currents.

west. When it meets the Gulf Stream, it seems to go beneath the latter, or to lose itself in some way not well understood. At any rate, the Gulf Stream has already acquired more eastward rotary motion than the part of the earth toward which it is flowing, and accordingly keeps to the right, or the *east;* and because its waters are warm, they stay on the surface. The result is that the British Isles feel the influence of the warm waters which bathe their coasts, and have a mean annual temperature equal to lands many degrees farther south.

And if one tropical current or drift flowing into the arctic regions can thus profoundly moderate the climate of much of Northwestern Europe, what might we not expect if several other similar currents were also permitted to flow unobstructedly into

the northern seas? When we know that a mild and springlike climate once prevailed over all the arctic regions, it is hard to refrain from imagining the lands and waters arranged in long, somewhat narrow strips, running northeast and southwest (in the Northern Hemisphere), in such a way as to steer the warm currents into the polar regions. It would seem that such an arrangement might so modify the polar climate as to abolish winter around the pole, and make it a region of perpetual spring. All this is only a theory; but some such arrangement there must have been, probably something which also profoundly affected the atmospheric currents; for it is certain that in former times, a climate of perpetual spring prevailed over the entire globe.

As already remarked, the ocean currents are quite *superficial* in their action, affecting the waters only a few hundred feet down. When a current is confined, as the Gulf Stream is confined between Florida and the islands of the West Indies, the current descends to the depth of nearly 2,000 feet. But in general, and in the open ocean, its depth is but slight, not affecting the life on even the banks which lie in its course. In the Florida Straits, the current attains a maximum rate of 5.25 miles an hour; but off the coast of Newfoundland, it is only from one to two miles an hour. The Gulf Stream is the strongest and most important of all the ocean currents.

The Continental Shelf. It should be remembered that the actual shore line is not what is regarded as the true margin of the ocean. This margin is always regarded by geologists as really beginning at the *100-fathom line,* as it is called, or the edge of the *continental shelf.* East of New York the continental shelf extends out about 100 miles with a grade of only 6 feet to the mile, a grade so slight that if the sea were to retire and the bottom were to be laid bare, it would take an experienced eye to detect any slope in the land at all. When the depth of 100 fathoms, or 600 feet, is reached, the bottom begins to drop away very rapidly to the deep oceanic abyss; and as we have already seen, the deepest portions of the oceans exist as rather wide strips along the margins of the continents.

It is often said that the oceans have encroached upon the lands to the extent of the width of this margin of shallow water over the continental shelf, as if the oceans had overflowed the lands to this extent. But it would be just as reasonable, and would be much more scientific — because furnishing a probable explanation of this phenomenon — to regard this continental shelf as *composed of materials washed by the sea down from the surface of the lands,* the 100-fathom line representing the distance to which these land materials are usually washed by the waters. Thus the edge of the con-

tinental shelf might be considered as *the edge of the dump;* and, indeed, this seems to be about the best way of looking at the matter. Of course, the edge of this great continental dump is not always exactly 600 feet below the water line. In the Gulf of Guinea, it begins at a depth of only 40 fathoms, or 240 feet; while off the coast of Ireland, it begins only at a depth of about 200 fathoms. Again, off the Atlantic border of the Southern States, there seems to be no well-marked boundary line between the shallow water and the deep abyss. But in general, such a margin of shallow water, sometimes narrow and sometimes much wider, surrounds all the lands; and the outer edge of this margin, at an average depth of about 600 feet, may be regarded as the true limits of the continents and the beginning of the ocean proper.

Deposits. A considerable variety of deposits is found at the bottom of the ocean; and it will be convenient to arrange a classification of these deposits, including also those which are found on the continental shelf. This classification is based on the work of the *Challenger* expedition (1872-1876), which marked the beginning of our real knowledge of the conditions at the bottom of the ocean. Before this time, statements about the ocean depths had been mere opinions, based on guesswork.

MARINE DEPOSITS

1. Littoral Deposits, extending out to the 100-fathom line	Shore-line Deposits, between high and low tides	Sands, Gravels, Muds, etc.	I. Terrigenous Deposits, derived from the land, except the calcareous accumulations
	Shallow-water Deposits, between low tide and the 100-fathom line	Sands, Gravels, Muds, Calcareous Beds, etc.	
2. Slope Deposits, laid down on the outer slope of the continental shelf, beyond the 100-fathom line		Coral Mud Volcanic Mud Green Mud and Sand Blue Mud Red Mud Calcareous Deposits	
3. Abysmal Deposits, laid down on the true ocean floor		Foraminiferal Ooze Pteropod Ooze Diatom Ooze Radiolarian Ooze Oceanic Red Clay	II. Pelagic Deposits, formed only in deep water far from land

The term *littoral* is sometimes restricted to characterize the shore line proper, between high and low tide; but here it seems best to extend it so as to include all the area covered by the water out to the edge of the continental shelf. But by subdivision of the littoral deposits, we have the *shore-line* deposits, formed between high and low water, and extending, in heavy storms, even above ordinary high water; and the *shallow-water* deposits, formed over the surface of the continental shelf out to the margin, or to the 100-fathom line.

The *shore-line deposits* thus constitute a very narrow ring around all the lands, estimated at only about 62,000 square miles for the whole world. The width of this ring at any particular place will depend on the slope of the bottom, and the amount of tidal rise and fall. On steep rocky shores, shore-line deposits may be wholly absent; while on wide mud flats at the heads of bays or near the margins of deltas, they may be of quite wide extent. Sand or gravel predominates on most beaches, and here distinct signs of stratification are not common; but on mud flats or marshes, where the surface is alternately exposed to sun and wind, and again covered by the rising tide, minutely laminated bedding is the rule, the beds being often characterized by ripple marks, rain prints, tracks of animals, and sun cracks, the latter often developing in the course of a few hours, or between tides, in hot, dry climates, like that of the Red Sea coast. Ripple marks, also, are not confined to the shore line, but have been observed in the open Atlantic and off the coast of Florida at a depth of over 600 feet. But the finding of any such marks on the surfaces of the ancient rocks is good evidence that the rock was formed in no very great depth of water. Unless we imagine the lands to be sinking, the shore-line deposits can never become thick or of much geological importance.

Shallow-water deposits begin at the margin of low tide and extend out to the edge of the continental shelf. The area here covered is about 10,000,000 square miles for the entire globe, or about 7 per cent of the ocean bottom; and those parts of the ocean covering this area are sometimes known as the *epicontinental* or *epiric* seas (Greek, *epi,* upon or above). Accordingly, the deposits here formed are of very great geological importance, especially since it is now understood that in the abysses of the ocean, no true stratified deposits are now being made.

On parts of the coast where no large rivers enter the sea for long distances, the materials on the shelf are all derived from the wear of the shore, and the assortment of these materials into coarse and fine deposits is carried on more extensively than in places where large rivers bring down their loads of silt. This sorting of materials is so complete in some localities that a belt of gravel may extend out to a distance of 10 miles from the shore, with another belt of sand beyond this, and mud still farther out, each of these belts extending along the shore for perhaps a hundred miles or more. Of course, there is no sharp line of demarcation between these belts; they grade into

one another imperceptibly. But beds of sand have been observed to extend out 100 or 150 miles from shore in some places, and for many hundreds of miles along the line parallel to the shore. The material of such a sandy bottom is nearly pure quartz sand; for these particles of quartz are the most enduring of all the substances derived from the disintegration of the rocks of the lands.

As the waves have little disturbing effect upon the bottom below a depth of 100 feet, it is chiefly along the more shallow parts of the epicontinental seas that effective transportation of materials takes place. Where shore currents are strong, the structure known as *cross-bedding,* or *current bedding,* is occasionally made. This structure is produced by the water pushing large quantities of sand or gravel forward over the top of a bank and dropping them down on the sheltered side in steeply inclined layers. The layers of a cross-bedded deposit are at a considerable angle, and the strata thus characterized may be found occurring between two horizontal bedding planes. Cross-bedding is more frequently observed in the older rocks which are composed of coarse sand or gravel. It is not confined to the littoral deposits of the ocean, but may occur in lakes and rivers, and, in fact, is far more frequently found in the deposits made by swiftly moving currents in streams and rivers. The *flow-and-plunge* style of bedding is an extreme type of cross-bedded structure, where the supply of sand or gravel is abundant and the current is very strong. In such an instance, the layers are wave-shaped, a yard or more long and six inches or a foot thick, each of these wavelike masses having been "produced by one fling of the waters." (Dana.) The size of these masses of sand or gravel is often much greater than the figures given above; and in one instance observed in the stratified Pleistocene deposits near New Haven, Connecticut, the thickness is six to eight feet. Such structures are never formed along any of our modern coasts, as the supply of material would not be sufficient to produce them; but they might be produced by swiftly rushing rivers in a flood, if enough loose materials were at hand.

In holes or depressions on the continental shelf, mud and clay will accumulate; for here the waters are less disturbed and therefore can drop finer materials. Such *mudholes* are found along the New Jersey coast near the entrance to New York harbor. Such mud deposits will of course wedge out laterally or dovetail into the sandy deposits around them.

Hypotheses. It is obvious that no great thickness of shallow-water or littoral deposits can take place *unless we suppose the sea bottom to be sinking;* for without such a subsidence of the land, the shallow waters on the continental shelf would soon be filled up, and thus the coast line would be built farther out into the ocean. But as the vast majority of the ancient deposits seem to have been formed by some disturbance or exchange of the sea and land, either by the land's subsiding or by the sea's rising and transgressing over the land, it will be of interest to consider just what would take place under such circumstances.

"If the subsidence be very slow, deposition may shoal the water and thus extend the coarse materials seaward; if it be rapid, deepening the water, fine sediment will be thrown down upon coarse; while if the rate of deposition and subsidence be nearly equal, the coarser material will form long, narrow bands, running parallel with the coast. Thus in the same vertical line may be accumulated many different kinds of sediment, corresponding to the different depths of water at the same spot. When traced laterally, beds of any given kind of material will eventually give way to those of another kind, either by gradual transition, or by thinning to an edge and dovetailing with the thin edges of the other beds."— *Scott.*

However, the attempt to read the ancient deposits in the light of such facts has not usually been very successful, since it is not easy to distinguish sands laid down by the sea from those laid down by lakes or large rivers, and since, in many respects, the deposits formed long ago seem to have taken place under conditions quite different from any with which we are acquainted in modern times. Especially is it difficult to interpret the manner in which any given ancient deposit was formed, unless we have some embedded forms of life or fossils to help us in our interpretation.

Organic Deposits on the Continental Shelf. Organic deposits are not very common on the continental shelf, though occasionally they are developed on a somewhat extensive scale. It will be proper to consider the characteristics of these organically formed deposits in some detail.

All animal life, whether on the land or in the sea, is, in the last analysis, *dependent upon plants* of some sort, the plants being the only ones that can appropriate the raw inorganic materials of the lands or the waters. Accordingly, the minute forms of floating vegetation, microscopic in size, furnish one of the chief supplies of food. Upon these microscopic plants (algæ) great numbers of small vegetable-feeding animals exist, such as worms, herbivorous gastropods, and other kinds of shellfish, many more living upon the larger kinds of algæ which also abound in many parts of the waters. Upon these small

animals, other carnivorous creatures subsist; so that these shallow waters are the home of a great variety of animal life, including the most of the commercial food-fishes.

The warm waters of the tropics contain a great variety of life; but, contrary to the general impression, it is in the cooler waters of the temperate and even of the arctic regions that the greatest amount of animal and plant life is found. One reason for this is that the warm waters can not hold nearly so much *dissolved oxygen* in solution as can the cooler waters, and oxygen is essential for both plant and animal life in the water as well as on the land. Another reason seems to be that certain bacteria swarm in the warm waters, but are absent or scarce in the cooler seas; and these bacteria interfere with other forms of life in two ways,— first by using up most of the nitrogen compounds which are necessary for the existence of other forms of life, and secondly by liberating free nitrogen from these compounds on which they subsist, this liberated nitrogen interfering with the solution of a sufficient amount of oxygen to provide for any profuse life in other forms. But in the cooler waters, these *denitrifying bacteria* are absent, more oxygen can be held in solution by the waters, and hence "we find their shores and bottoms thickly populated with an abundance of organisms, both animal and vegetable." (Pirsson.)

Shellfish, or *mollusks,* of various kinds supply a large amount of the calcareous materials for the formation of shallow-water limestones. These animals secrete $CaCO_3$ directly from the sea water, and their shells often accumulate in large banks; and when such banks lie below the limit of violent wave agitation, these shells may be unbroken, and may lie embedded in much finer material, which may be composed of other substances besides calcium carbonate. More often, however, the shells are broken up into fine fragments by the waves, thus forming shell-sand or even mud; and in this state, chemical action soon converts the mass into a solid limestone. Crustaceans and fishes which feed upon these mollusks materially assist in breaking up the shells and forming the calcareous sand and mud in which many unbroken shells may become embedded.

The *Echinodermata* are a group of marine animals which includes the starfishes, sea urchins, crinoids (sea lilies), and sand dollars. Their skeletons are composed largely of calcium carbonate, and are thus capable of forming considerable beds of limestone. "At the present day, however, they seldom build up any extensive masses unassisted, but in former ages of the world's history they did so on a great scale." (Scott.) The

most important (geologically) of this group are the *crinoids*, which have been considered rather rare in our modern seas, and which, when they do occur, are found chiefly in the deeper waters. But very extensive limestones of the ancient rocks are composed almost entirely of their broken stems and calyxes.

But by far the most important limestone makers of our modern seas are the *corals*. They comprise a great variety of forms, sizes, and habits of growth, though it is only the social or colonial types, or reef-building corals, that are conspicuous as rock makers. The *solitary corals*, which are found in our modern oceans down to very deep waters, are not of geological importance to-day, though their fossils are often found in the older geological deposits which compose our present lands. The *reef builders* are confined to clear, warm water which never gets colder than 68° F., and which has the full amount of salinity. They do not flourish below a depth of 150 feet, and most of them are confined to depths of less than 120 feet. Thus they are never found near the mouths of large rivers, for such rivers bring down fresh water more or less laden with sediment. They seem to thrive best in the face of the steady ocean currents; for such waters not only bring them plenty of food (and as the creatures are themselves stationary, they have to depend upon what the waters bring them), but also prevent the accumulation of calcareous silt and *débris* which would otherwise smother the polyps.

"Saville-Kent, indeed, insists that reef building is influenced by *temperature* much more than by the species of corals, for he finds that the same species which build the reefs in tropical waters are not reef-building in extra-tropical regions. He further holds that it is only in the shallower water where precipitation of lime is caused by evaporation that coral conglomerates and limestones occur. Corals as such are, however, by no means restricted to the tropics. *Astrangea danæ* grows on the southern shore of Massachusetts at Woods Holl, and *Lophohelia prolifera* and *Dendrophyllia ramea* form dense beds at a depth of from 100 to 200 fathoms [600 to 1,200 feet] off the coasts of Norway, Scotland, and Portugal."— *Grabau, "Principles of Stratigraphy," pp. 391, 392; "The Great Barrier Reef of Australia," p. 98.*

Many varieties of other animals hang around the coral reefs, feeding upon the coral polyps, and breaking up the sharp points of their skeletons or boring into the coral mass. Certain calcium-secreting seaweeds, called *nullipores*, contribute very materially to the slowly accumulating submarine mountain, which in many instances seems to rise directly out of the profound depths of the deeper ocean, though the living corals themselves are confined to the extremely shallow levels of the surface waters.

Some of the problems connected with the formation of coral reefs and coral islands will be more properly considered in the next chapter.

The Muds. Beyond the 100-fathom line, on the outer slope of the continental shelf, are the so-called *muds*, of various colors and varying composition, these muds being a mixture of minerals derived from the lands, in a state of very fine mechanical division, but differing from true clay in that they are not chemically decomposed.

1. *Blue Mud.* Very minutely divided grains of quartz, with some clay, and from 7 to 25 per cent of calcium carbonate, mostly comprise this deposit; but minute quantities of other minerals derived from the land are also present. The remains of diatoms, radiolarians, and the spicules of sponges contribute organically formed particles of silica; while the shells of Foraminifera which live in the surface waters fall upon the continental slope and help to furnish the calcareous materials found in this blue mud. The blue color of this mud is due to the presence of the organic matter which prevents the oxidation of the sulphide of iron which it contains. In places, this blue color is replaced by a greenish tint, caused by minute grains of *glauconite,* a silicate of magnesia, iron, and potash. More or less glauconite is almost always present in these blue-mud deposits, sometimes predominating and forming a *green mud.*

These blue muds are estimated to cover 14,000,000 square miles of the ocean bottom, the total area of the slope deposits being only about 18,000,000 square miles. Thus these blue muds are by far the most extensive deposits in the deep seas which are derived in any measure from the lands. They often extend from the edge of the continental shelf far out beyond the 6,000-foot line.

2. *Red Mud.* This is found chiefly in the Yellow Sea to the east of China, and on the Atlantic coast of Brazil. The red color is due to Fe_2O_3 which is contained in the *laterite* brought down by the neighboring rivers. The shells of Foraminifera are present in this red mud; but those of radiolarians are rare.

3. *Greensand.* This is not sand in the ordinary sense of the term, but its granular appearance is due to chemically formed grains of *glauconite,* with about an equal amount of calcium carbonate. These glauconite sands often occur within the 100-fathom line, and usually in shallower water than the true muds. They are interesting geologically from the fact that they resemble in composition certain beds associated with the ancient *chalk* deposits, such as those of Southern England and

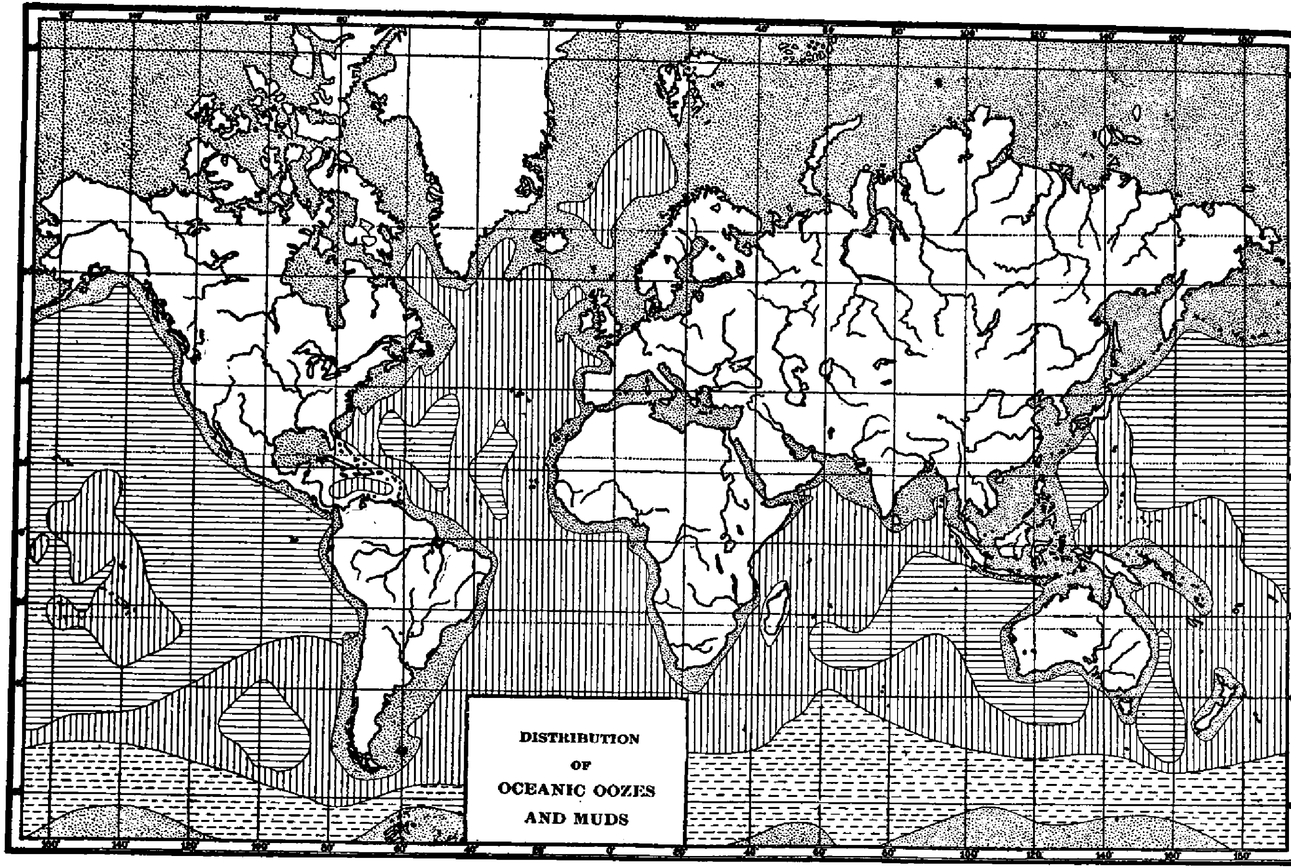

FIG. 105. Distribution of oceanic oozes. *Dotted*, areas of terrigenous deposits; *vertical ruling*, areas of globigerina ooze and coral muds; *horizontal ruling*, areas of red clay; *horizontal broken lines*, areas of diatom ooze. (After Murray and Renard.)

Kansas. These modern glauconite deposits cover about 1,000,000 square miles.

Abysmal Deposits. Aside from the scanty volcanic deposits found alike on the bottom of the deep seas and on all other parts of the ocean floor, the abysmal accumulations are not directly derived from the land, but consist of substances secreted by marine organisms which fall to the bottom and lie there in a far advanced state of decomposition. These abysmal deposits occur only far from land, beyond the 6,000-foot line; and they

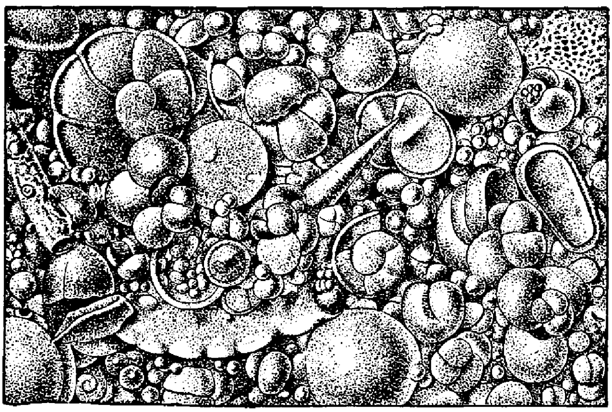

FIG. 106. Globigerina ooze. × 20. (After Murray and Renard.)

accumulate very slowly, since the bones of animals long extinct lie exposed on the ocean floor and not yet covered by the organic accumulations.

1. *Foraminiferal Ooze.* The Foraminifera are minute animals allied to the common amœba, which nevertheless secrete beautifully formed shells of calcium carbonate ($CaCO_3$). They live in uncounted myriads in the open surface waters of the ocean, principally in the warmer waters, though they often follow these warm currents into the northern regions. Murray and Renard have calculated that throughout the ocean in general, every square mile of the surface water, extending to the depth of 600 feet, or the limit to which light penetrates, contains on an average at least sixteen tons of floating carbonate of lime, in the form of the shells of minute pelagic organisms. When these organisms die, their delicate spiral shells drop in clouds to the bottom of the ocean. Although these shells fall to the bottom of most of the ocean waters, the silt from the lands predominates in those regions which are near the shore; and it is only when the foraminiferal shells are present in sufficient quantity to amount to about 30 per cent or more, that the

bottom ooze is called foraminiferal. Other organisms which also secrete calcium carbonate add their quota to these deposits; and in some places in the medium depths of the ocean, the ooze may consist of 90 per cent calcium carbonate. In such instances, it is nearly white, like chalk; and, indeed, the ancient chalk deposits were formed almost entirely of such materials, though, from the frequent alternation of these chalk beds (in the older rocks) with beds containing plants and other remains from the lands, these ancient chalk beds are thought to have been formed in some way near the shore — a very inadequate explanation.

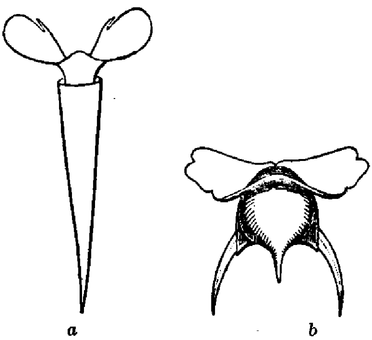

FIG. 107. Modern shell-bearing pteropods. *a*, *Styliola vitrea*, about two and one half times natural size; *b*, *Cavolinia tridentata*, approximately natural size. (After Verrill and Smith.) (After Murray and Renard.)

As a kind of the Foraminifera belonging to the genus *Globigerina* constitute the majority of the present animals forming this ooze, these beds have often been called the *globigerina ooze* (Fig. 106). These deposits cover a very wide extent of the total oceanic area, amounting to some 49,520,000 square miles. They are especially characteristic of the Atlantic bottom, though they are present in all except the polar oceans. They range in depths from about 2,400 feet down to nearly 18,000 feet, though they become rarer below 15,000 feet, because the percentage of carbon dioxide increases in these depths, and this carbonic acid in solution dissolves the shells.

2. *Pteropod Ooze.* The pteropods are small mollusks with thin, delicate shells, and they live in the surface waters of the warmer oceans. In the shallow waters, their shells are outnumbered by other materials; but in some parts of the Atlantic, in depths of less than 12,000 feet, there are so many of these pteropod shells among the foraminiferal ooze that these deposits have received the name of the *pteropod ooze* (Fig. 108). These pteropod shells abound in some of the older rocks known as the Ordovician limestones, which are found in various parts of America and Europe, as well as elsewhere.

3. *Radiolarian Ooze.* The Radiolaria are minute animals which, instead of secreting calcium carbonate, form tests of silicon dioxide (SiO_2). Their shells are small, delicate, and of a very beautiful structure; and these animals live both at the surface and at the bottom of the ocean. But all of the radio-

larian oozes are deep-sea formations, and are found to-day at depths between 10,000 and 20,000 feet.

However, it is a very interesting fact in this connection that the radiolarian deposits found in the older rocks, often called *radiolarite,* quite common in the Jurassic rocks of the Alps, are very closely associated with limestone breccias or gray muds, in such a way as to show that fairly strong currents must have been instrumental in producing them. Certainly it would take a very profound disturbance of the ocean, reaching to its very bottom waters, to produce any such deposit in our modern world. It is probable that the cherty limestones of the Onon-

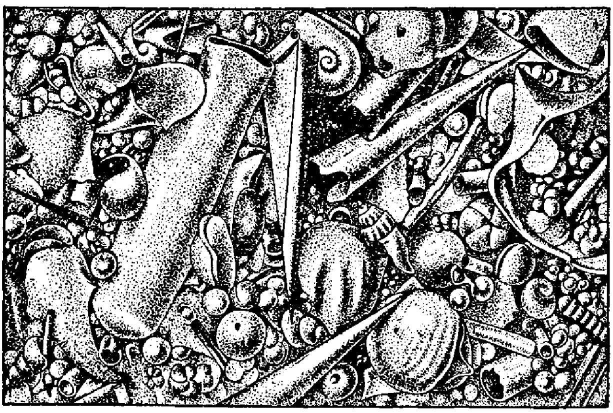

FIG. 108. Pteropod ooze, magnified 10 times. (After Murray and Renard.)

daga beds of Western New York, as well as the so-called *Corniferous limestones* of these same parts, were also formed by radiolarian deposits which became intimately mixed with deposits of calcium carbonate and were subsequently hardened into limestone.

The shells of radiolarians occur in most of the modern marine deposits; but only when they comprise 20 per cent or more of a deposit is it called a radiolarian ooze. Such conditions occur only in the more profound depths of the Pacific and Indian oceans, between 2,300 and 5,000 fathoms below the surface. The ooze covers about 2,290,000 square miles.

4. *Diatom Ooze.* The frustules of *diatoms,* which are microscopic plants secreting silica, occur in both fresh waters and salt; but it is only in the Antarctic Ocean, and in a small area in the North Pacific, that the marine diatoms accumulate in quantities of importance. This ooze is found in depths between 600 and 2,000 fathoms, and it covers an area of over 11,000,000

square miles (Fig. 105). Such a marine diatom ooze resembles the similar deposit found in fresh water, but may be distinguished from the latter by having foraminiferal shells and radiolarian tests mixed with it.

5. *Red Clay.* All the deepest parts of the ocean bottom are covered by a deposit called the red clay. It is composed of the decayed residue of materials derived from volcanic dust, though its exact origin is not well understood. It covers some 51,500,000 square miles, four fifths of this area being in the Pacific.

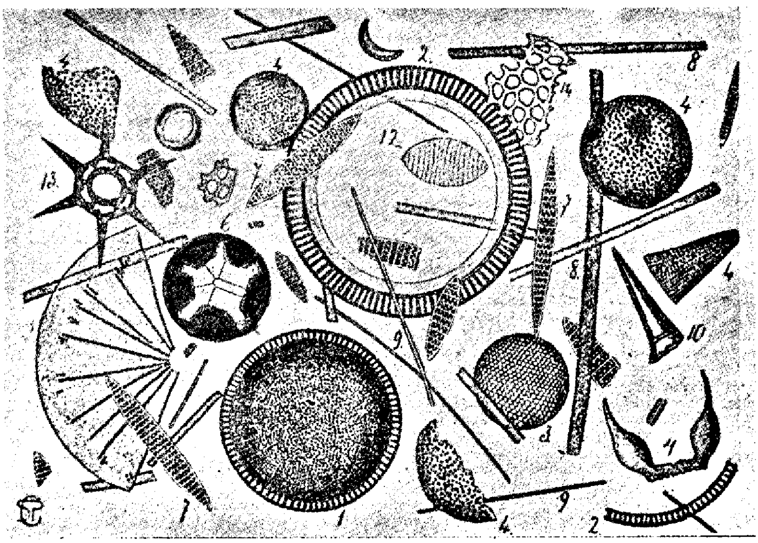

FIG. 109. Many species of diatoms washed out of Antarctic diatom ooze. × 300. (From Krümmel's *Oceanographie.*)

Conclusions. From all this study, it has become evident that these modern deposits on the bottom of the oceans do not help us much in explaining how the ancient sandstones, slates, and limestones were actually formed. Certainly these ancient beds, with their distinctly stratified layers, *often alternating with coal seams or coarse conglomerates,* were not formed at the bottom of the ocean. It used to be taught that if the bottom of the ocean could be lifted up and exposed to erosion, we should see the counterpart of the rocks which now compose our mountains and hills. True, the *fossils* found in these ancient beds are often similar to or identical with marine forms now living at great depths in the ocean; but the *texture of the two kinds of deposits is entirely different,* and we do not know of any modern processes by which such an alternation of marine and land forms is now being made.

CHAPTER X

Life: Its Geological Effects

In this chapter, we shall consider those organic accumulations which are forming under modern conditions and which are of geological importance. These accumulations are produced by a wide variety of living creatures, plants and animals; yet one universal condition seems to be essential for them all, namely, a *complete covering of water fresh or salt, to exclude the agencies of oxidation.* A complete covering of water is not so essential for the preservation of the *calcareous* and *siliceous* deposits as it is for the *carbonaceous* ones; but the former are produced only under water, and so they also partake of the same conditions which have contributed to preserve the carbonaceous accumulations.

Moors. The last-named deposits are found in connection with the lands, and are produced in localities which are scientifically termed *moors;* these being, however, classified under three divisions: *marshes, swamps,* and *bogs.*

1. *Marshes.* The marsh is a low moor near the sea. It is covered by a vegetation consisting chiefly of sedges and eelgrasses of the pond lily family, if the flat is permanently covered by the water. If the marsh is only partly covered by the water, the eelgrass will be replaced by other types of marsh grass. The slow accumulation of the decaying tissues of these plants contributes to the making of a sort of salt-water peat, which, however, is meager in amount, and quite completely mixed with earthy matter; for the only way in which such marshes are now being buried is by the high tides' spreading silt over them, or by very scanty deposits of wind-blown sand. Such salt marshes are common in various places along the coasts of most of the continents.

In the tropics, salt-grass marshes are replaced by *mangrove marshes.* Mangroves are trees from 5 to 60 feet in height which can grow in salt or brackish water, and which send out numerous long aërial roots from the lower parts of the stems, or even from the branches, like the banyan tree. Even seeds still attached will send out roots which extend down to the mud and thus take root. In this way, dense thickets of these plants spread over marine marshes in the tropics which are sufficiently shallow and protected from the waves. Like the cypresses of Florida and other Southern States, the mangroves

have *air roots,* which are erect or kneed branches of the real roots, and which project above the mud, and are provided with minute openings through which air passes down to the submerged part of the roots, thus providing oxygen for the plants. It is not well understood how much carbonaceous material may be now accumulating in these tropical marshes; but at the most, it is not of any great thickness.

In all peat beds *to which salt water has access,* hydrogen *sulphide* (H_2S) is generated in large quantities. Apparently this is on account of the presence of certain bacteria which act on the sulphates contained in sea water, these bacteria thriving in the presence of decaying vegetable matter. By chemical reaction, this hydrogen sulphide unites with whatever iron compounds are present in available form, and produces *iron pyrite.* The latter substance is commonly found in salt-marsh deposits. This and other sulphides are also present in many of the *ancient coals,* proving that sea water had access to these vegetable masses before they were buried; for hydrogen sulphide does not occur in fresh-water vegetable deposits.

2. *Fresh-Water Swamps.* In lakes, water lilies and other plants will sometimes begin to grow where the water is nearly 25 feet deep; but the most important peat-forming plants do not grow in lake water that is more than about two feet deep. The chief ones concerned in producing the peat are the cattails, rushes, sedges, and bulrushes, with *Hypnum* and *Sphagnum* mosses near the surface of the water in some of the swamps of Continental Europe and some few other parts of the world. When a swamp has become partly filled up with the accumulations of these materials, alders, cedars, tamaracks, and a few other hydrophytes may grow in it, the decay of their trunks and roots adding very materially to the accumulating mass. If such a swamp is situated near the mouth of a large river, it may become unusually flooded in some freshet time, and a deep layer of silt may be spread out over it, thus burying the peat. In this way, an alternation of strata would be formed. But such a process could not be often repeated under any modern conditions, *unless we suppose that the swamp area is subject to gradual or periodic subsidence;* and we do not know of any such examples in our modern world.

The *Okefenokee Swamp* of Southern Georgia contains a peat bed some 10 feet thick; while the *Dismal Swamp* of Virginia and North Carolina has a deposit some 15 feet thick. These swamps give no indications of being in process of further submergence and burial under silt or sand; and their bottoms rest directly on beds of the older geological formations (Tertiary).

3. *Bogs.* These are moors situated in the upland districts of Great Britain and Northern Europe, as well as of Canada, the northern United States, and Northern Asia. Sedges, pondweeds, bulrushes, and the peat mosses, especially *Sphagnum,* are the common bog plants, with heather in some localities.

In Northern Germany, the upland moors usually consist of an older, much decayed *Sphagnum* peat, with another layer of *Sphagnum* above it, the two being separated by a dividing layer of more terrestrial-growing plants, these three layers being surmounted by a more modern layer of heaths, lichens, etc. "Owing to the fact that the old Roman roads were built upon the dividing layer of terrestrial peat, it becomes possible to measure the rate of growth of the upper peat layer, which must have accumulated during the past two thousand years." (Grabau.) This alternation of different kinds of vegetable material is, however, not due to anything like a submergence or burial of the deposit, but rather to the fact that the *Sphagnum* tends to dry up the water through capillarity and evaporation, which causes its own death; and only after other plants and more water have returned, can the *Sphagnum* again obtain a foothold, to be again replaced by the modern growth of heaths and lichens.

Peat. The conversion of fresh vegetable matter into *peat* is a process quite similar to the formation of charcoal, only not so complete. The oxidation which would become complete in the free air is smothered; but some of the hydrogen is removed as H_2O, some of the carbon as CO_2, and some of both as CH_4, or marsh gas. What remains is much richer is carbon and leaner in hydrogen than were the original substances; but the total amount has been much decreased, and in this semi-decomposed condition is known as *peat.* In color, when dried, it varies from a pale yellow or light brown to a dark brown; and when wet, it is almost black. It always shows its vegetable composition, in the fibers running through the mass; but there are no well-preserved plant remains in it.

The arrest of the decay in these peat swamps and bogs seems to be due to the fact that the bacteria, which are chiefly concerned in the decaying processes, generate waste products which, if not removed, tend to stop further bacterial growth, just as alcoholic fermentation tends to kill the bacteria which produce it, since these waste products are *antiseptic* in their nature. This would also explain why the bones of men and prehistoric animals have been found in peat bogs in a good state of preservation, though buried for hundreds or thousands of years.

The arctic plains, or *tundras,* also have extensive peat deposits, which, however, rest upon a substratum of frozen soil

FIG. 110. A fossil cycad fern (*Dictyopteris sub-brongniartii*), from the Coal Measures of France. (Hardin, U. S. G. S.)

or ice which remains frozen all the year round. In many places, these tundra deposits contain the remains of prehistoric animals which do not now live in these regions, showing that these deposits have continued from remote times. Along the Yukon, such beds are seen from 8 to 10 feet thick, "and nearly always frozen solid." (Russell.) On the island of Anticosti, in the Gulf of St. Lawrence, are peat beds from 100 to 1,000 acres in extent, with a thickness of ten feet or more, which rest "directly upon the eroded limestone surface of early Paleozoic age."

FIG. 111. Village on a coral island, San Blas Coast, Panama. (Smithsonian Report, 1909.)

(Grabau.) The lower parts of these beds often contain tests of sea urchins, with fragments of lobsters, crabs, gastropods, and other marine animals.

Summary. From this survey of the modern peat-forming deposits, we do not obtain much help in understanding how the ancient coal beds were formed. Not only do we have *no modern analogies,* in the way of large masses of vegetable matter now being buried by gravels, sands, or muds; but the *exquisite preservation* of many of the ancient remains (Fig. 110), the way in which the beds of land plants *alternate* with beds containing crinoids, corals, and other deep-sea forms, as well as the *character of the plants themselves* in many of the beds, which often consist of trees and plants which do not grow near swamps or bogs,— all these facts show conclusively that we have in these ancient coal beds a problem of no little difficulty, if we feel

obliged to explain them on the basis of the modern action of the processes of nature.

Iron Ores. All the rocks and soils contain *iron* in varying proportions. In the presence of decaying organic matter, such as is found in peat bogs and marshes, the insoluble ferric form of the oxide is converted into ferrous oxide, which is soluble, and is carried away by the water. Under certain conditions, however, this dissolved iron may be acted upon by certain bacteria, known as *iron bacteria,* which may reverse this process, and indirectly may produce extensive beds of limonite, or *bog iron ore,* as it is often called; or they may even give rise to similarly extensive beds of ferrous carbonate (*siderite,* $FeCO_3$). Such beds of iron ore extend from Vermont and New York southward to Alabama, and may have been formed in somewhat this way by bacterial action and concentration of the insoluble ores produced thereby, this process having been going on for the long periods of time since the ancient vegetable beds were laid down.

Calcium and Magnesium Carbonates. It used to be thought that the chemical precipitation of lime and magnesia as limestones and dolomites is not now going on. But it is now known that both limestones and dolomites are being formed as *chemical precipitates* to some extent, and as *organic deposits* produced by bacteria and algæ to a very considerable extent. Certainly the quantities of limestone which are now being formed through the action of animal and plant life are very considerable; and the consideration of how these modern deposits are being formed will help us in our study of those deposits of these materials which we find in the ancient rocks. Our modern limestones are chiefly being formed by the coral reef builders of the ocean; and we must now give consideration to them.

Coral Reefs. Coral reefs are complex in their formation, and *coral polyps* may sometimes play only a minor part in this work. *Nullipores,* or calcareous *algæ,* are almost always contributory; and in some instances, they seem to be even the principal agents in the accumulation of the limestone. But *millepores* also are abundant; while among the fossil coral beds, *sponges* and *bryozoa* are often the most important calcareous organisms.

According to the time-honored classification, there are three types of coral reefs, the *fringing reef,* the *barrier reef,* and the *atoll.* But in the factors influencing their geographical distri-

bution, as well as in their growth and internal structure, *all coral reefs are very much alike.* And although all the older coral deposits, as revealed to us in the fossiliferous rocks, are invariably associated with other deposits from the lands, and often interstratified with them, the lone atolls of the mid-Pacific do not in structure or in the factors controlling their existence and growth differ essentially from those fringing volcanic and other islands. And there is no sharp line of division between these three classes, but they grade off into one another in each direction.

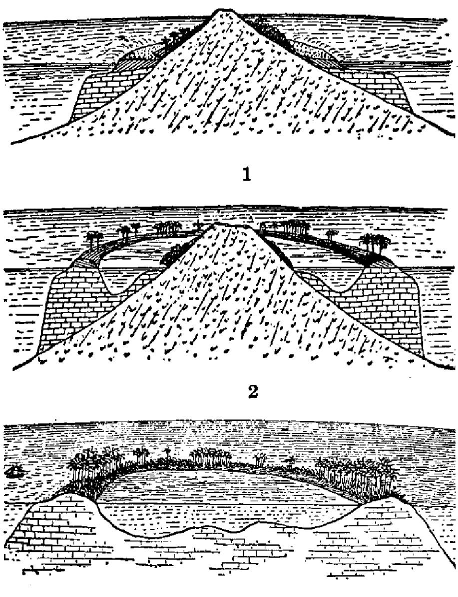
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FIG. 112. Sections through a coral island, illustrating the theory of its supposed change, after a long period of time, from a fringing reef (1) to a barrier reef (2), and finally into an atoll (3). This is the theory of Darwin and Dana, now discredited. (From "The New International Encyclopædia," by permission.)

The typical *fringing reef,* or shore reef, is located along the shore of some island or larger body of land, and a distinct channel exists between it and the land. The side toward this channel is usually lower than the outer side, and does not have so many living forms upon it; for here the water is sometimes freshened by water from the land, and is always more laden with sediment, while the tidal currents interfere with the growth of the polyps. But on the seaward side, which is always oriented so as to face the prevailing winds and currents, the reef is often abrupt or at least quite steep, though it descends usually into comparatively shallow water.

Fringing reefs are found along the coasts of Florida, and around nearly all the islands of the West Indies. They are found along both shores of the Red Sea, and along the coasts of Mozambique and Madagascar, as well as around many of the islands of the Indian Ocean. In the Pacific, they occur on the shores of such well-known islands as the New Hebrides, the Hawaiian, Solomon, Friendly, and Samoan, with many others.

A *barrier reef* is much like a fringing reef, except that it is farther from the shore, and accordingly has a deeper channel between it and the land, with deeper water also on its seaward side. According to the theory of Murray and A. Agassiz, a barrier reef is simply a fringing reef that has progressed seaward by the natural growth of the front of the seaward side, growing outward upon the talus of coral detritus in front, and by the enlargement of the landward channel through the solution and the disintegration of the dead rock on that side. Others (Darwin and Dana) explain the barrier reef by the theory of the *gradual subsidence* of the bottom and the simultaneous upward growth of the corals on the outer face of the reef. These two theories are also invoked to explain the atolls; and there is still much controversy as to which explanation is correct, or whether either is.

The *Great Barrier Reef* of Australia extends along the northeast coast, with some interruptions, for 1,250 miles; and in places, its outward wall is 90 miles from the coast and drops away into water 1,800 feet deep. It is "a great submarine wall or terrace, fronting the whole northeast coast of Australia, resting at each end in shallow water, but rising from very great depths about the center. Its upper surface forms a plateau, covered by 10 to 30 fathoms of water, but studded all over with steep-sided, blocklike masses which rise up to low-water level." (Jukes-Browne.)

The Fiji Islands, the Society Islands, and New Caledonia have barrier reefs. The one around the latter island is 400 miles long and about 10 miles from the shore.

Atolls are ring-shaped reefs, sometimes broken at one or more places by channels which lead into the interior lakelike space of water, which is called the *lagoon*. The water in the lagoon is shallow; but on the outside, it is sometimes a mile deep, always far deeper than the depth in which corals can begin their work. The openings in the wall of the atoll are generally on the leeward side, and thus the water of the lagoon is protected. Within the lagoon are numerous kinds of creatures, including fishes and especially sharks.

Atolls are scattered all across the Pacific and the Indian Ocean. There are no atolls in the Atlantic, though the Bermudas have fringing reefs, which represent the most northerly range of the corals of the reef-building kinds. However, it has been contended that some of the same species which build reefs in the tropics exist elsewhere but do not build reefs in more northerly or southerly regions; and from this, it would seem that reef building is *more controlled by temperature and other conditions than by the mere species of corals.* It seems that

coral conglomerates and limestones can be consolidated by the precipitation of the lime only in shallow and warm water where evaporation is extensive. But true corals are found off the coasts of Norway and Scotland, and at depths of 1,000 feet, where they form dense beds. One species grows at Woods Hole, on the south shore of Massachusetts.

It may be that, if the ocean was warmer down to a much greater depth, as seems to have been the case, in ancient times, the reef-building corals could lay the foundation of their atolls and other reefs *at much greater depths* than that in which they can work at present. It is of course possible that many of the atolls may have started from the slightly submerged tops of volcanoes, or again it is possible that a subsidence of the bottom has taken place. But it seems to the present writer that in a much warmer water down deep in the ocean, which we know there *must have been* when the luxuriant Miocene flora was growing in the arctic regions, these coral reefs now found rising from such deep waters may have started on slightly elevated parts of the bottom, but much below the point at which these corals now live.

Some years ago borings were made in one of the typical atolls (Funafuti, in the Ellice Island group), and they showed that the coral rock extended down more than 1,000 feet. But more recently borings have been made in another Pacific atoll, and also in Bermuda, which show "only a relatively thin capping of it on the volcanic rock, which forms the main masses rising from the ocean depths." (Pirsson.) There have also been found, in various places in the tropical waters, shallow water platforms which are about the proper depth for corals to begin upon, but which have no such corals as yet; hence other platforms of similar character may have served for the beginning of some of the barrier reefs and atolls. (Vaughan.) It has also been shown that the water of the lagoons, so far from dissolving the rock and thus enlarging the lagoons, is *really precipitating calcium carbonate* and thus tending to fill them up. Taken all together, it does not seem that any gradual subsidence of the ocean bottom is needed to account for the formation of these coral reefs, or even that any unreasonably long time is required for their formation.

"The theoretical possibility of the progressive change of a fringing reef into a barrier and later into an atoll, according to the Darwin-Dana hypothesis, may not be denied; but no instance of such a transformation has yet been discovered."— *T. W. Vaughan, "Smithsonian Report," 1917, p. 238.*

However, it conveys a wholly wrong impression to speak as if the coral reef were *built up* by the industry of the polyps. These furnish some of the materials, while perhaps an equal amount is supplied by the coral-like seaweeds called *nullipores;* but the actual work of converting the remains of these and of many other kinds of organisms into compact limestone rock is

performed partly by the waves, in grinding up into lime-sand and lime-mud these organic remains, and partly by the *chemical action* of cementing or "setting" the mass together.

After a storm, the water around a coral reef is milky for great distances, because of the fine limerock flour held in suspension. Such suspended calcareous material has been observed at a distance of 8 or 12 miles from the reef. From 1.5 to 2 inches of coral mud was in one instance deposited between two tides, after a prolonged storm. (Agassiz.) Some of this rock material is dissolved and afterwards precipitated as $CaCO_3$, thus cementing the whole into a firm rock, which is so hard that Darwin found he could break off a piece only with a chisel. In all the older portions of the reef, all signs of stratification or of its organic structure are lost, much of the mass even *becoming crystalline,* like the older fossiliferous limestones. Even under the microscope, no trace of organic structure can be seen, so completely has the substance been changed.

In some instances, even in modern reefs, the limestone is converted more or less completely into *dolomite,* $CaMg(CO_3)_2$. Rocks which are not entirely changed into pure dolomite, but which contain a considerable amount of magnesia, are often called *dolomite* or dolomite-limestone. It is now known that some of the algæ contributing to the formation of the limestone also secrete a considerable amount of magnesium carbonate. Vast thicknesses of dolomitic limestone are found in the Alps and elsewhere; and in some instances, we find limestones and dolomites *interstratified,* which are still harder to explain. These are probably due to differences in the materials deposited, the limestone coming from one locality and the dolomite from another. This would imply that there were originally magnesian deposits available for such work of sedimentation.

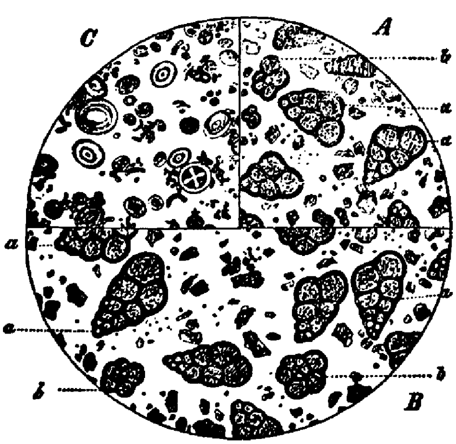

FIG. 113. Microscopic view of white chalk, showing the Foraminifera, etc. *A*, chalk from Sussex, England; *B*, chalk from Farafra, Libyan desert. Both × 60. *a*, *Textularia globulosa*; *b*, *Rotalia (Discorbina) marginata.* *C*, dried residue of milky chalk water with coccoliths. × 700. (After Grabau and Zittel.)

Chalk. Two quite different kinds of chalky limestones are found among the older rocks, though both are sometimes classed under the

FIG. 114. Quarry in Annona chalk, Whitecliffs, Arkansas. (Stanton, U. S. G. S.)

head of *chalk* deposits. One of these contains a large percentage of *foraminiferal shells,* with microscopic calcareous algæ and other fragments. Its organic content is quite similar to the foraminiferal or globigerina ooze now found on the floor of the Atlantic; though some authorities make a distinction between the *species* of the two deposits, and argue that the kinds of life found in the chalk do not necessarily indicate deep, abysmal deposits. It is not strange that a distinction can be made out between the species in the ancient as distinguished from the modern globigerina ooze; but it may be questioned whether, after all, such specific distinctions mean very much. On the other hand, it is truly remarkable to find deposits like that of the chalk, which probably was produced at the bottom of the deep ocean, systematically interbedded with deposits containing fossils from the lands, indicating that these two kinds of organisms, so different in their origin, had somehow become mixed up together.

FIG. 115. A fragment of nummulitic limestone, from the Pyrenees Mountains. The shells appear in section and are of natural size. (After Haas.)

The other chalklike deposit is that formed from the shells of *nummulites,* Foraminifera which are not so minute as those of the chalk, being nearly an inch in size. These

do not live in the surface waters of the ocean, but live *entirely on the bottom of the deeper waters;* but their remains are now found composing vast masses of mountains stretching from Central Europe almost to India, the stones of the pyramids and of the Sphinx in Egypt being composed of such nummulitic limestone.

Other Limestones. The *Bryozoa* are regarded as of a somewhat higher grade of organization than the coral polyps, but they form structures of calcium carbonate which can not always be readily distinguished from those produced by corals, except by a trained observer. The living Bryozoa form delicate leaflike structures of limestone material, or are found incrusting

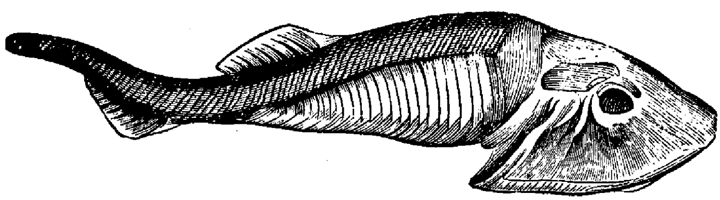

FIG. 116. A Devonian ostracoderm, *Cephalaspis lyellii.*

rocks, or seaweeds, or other substances on the sea floor. The ancient Bryozoa, however, seem to have built branching masses which often in accumulation produce large limestones. Along the coasts of the Crimea are seen cliffs which contain reeflike mounds built by these ancient Bryozoa; but oftener their remains are found spread out as wide sheets.

The shells of the Brachiopoda and of the Mollusca contributed very largely to the formation of limestones as we find them in the ancient rocks; though there are only a few localities where extensive modern accumulations of limestone are being produced by any of these creatures, these being chiefly formed by oysters and other bivalves. Some quite extensive beds of limestone were built up by some ancient kinds of *Ammonites,* related to the modern Nautilus. Other related types, which, however, have straight shells instead of coiled ones, also were an important source of the limestone material of many rocks (*Orthoceras* limestones).

Siliceous Deposits. Chief among the siliceous deposits of organic origin may be mentioned the *radiolarian oozes.* These are typical deep-sea deposits, being found only in the deeper parts of the ocean, near to or associated with the red clay of the very deepest parts. The island of Barbados, however, has a

colored clay largely composed of radiolarians similar to those now found in the deep waters of the Pacific. An intensely blood-red rock composed of a radiolarian mud constitutes certain portions of the Austrian Alps, the organisms being similar to those

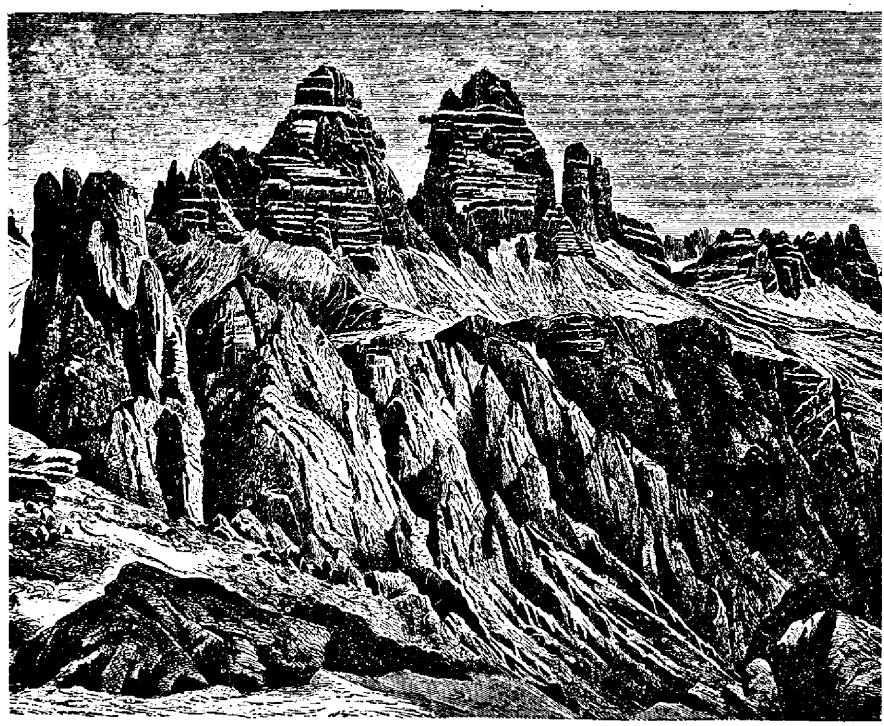

FIG. 117. "The Dolomites," in the Tirol of the Austrian Alps. These rocks are composed largely of the remains of minute lime-secreting marine plants or algæ. (After Ratzel and Grabau.)

found from 2 to 4 miles down in the Pacific, these rocks being now about as high above the water as they formerly were below it.

Similar deposits of siliceous radiolarians occur in the Lower Carboniferous beds of the Rhine, as well as in various parts of Great Britain and elsewhere. They often *alternate with limestone breccias or argillaceous marls,* indicating a profound disturbance of the ocean bottom. Nowhere on earth to-day do we find anything like an approach to such a strange combination of conditions as is thus indicated.

Microscopic plants called *diatoms* also contribute very materially to the production of siliceous deposits. The structure which a diatom forms is called a *frustule,* and it consists of two

parts which fit together like the two parts of a pill box. In some fresh-water ponds and lakes, these frustules accumulate to a considerable depth, forming a chalklike deposit, which, however, is not composed of calcium carbonate, but of *silica,* and which will serve as a polishing powder for metals. When pure, such a deposit is called *tripolite;* and when impure, *diatomaceous earth.*

These siliceous deposits in fresh water are of very limited extent, and quite unimportant geologically; but diatoms live in the ocean also, and their deposits are spread out over an area of some 10,000,000 square miles in the South Pacific and Antarctic oceans, forming the so-called *diatom oozes.* An area of some 40,000 square miles in the North Pacific is also covered with diatom deposits. They occur at an average depth of 9,000 feet, or a mile and a half. Radiolarian remains and the siliceous spicules of sponges are usually found mingled among them.

Diatoms are quite frequently found among the ancient rocks, forming considerable areas in some instances. It has been thought that the slow accumulation of diatoms on the bottom of some ancient shallow sea was the chief source of the organic materials forming the oil and gas found in California and elsewhere. This is of course only a supposition; for although diatomaceous rocks are associated with these hydrocarbons, as at Lompoc (Fig. 118), California, and in other places, yet here we

FIG. 118. Quarries near Lompoc, California. Some of the strata here are full of fossil fishes. The beds are composed of siliceous diatoms, which, falling in great quantities upon the shoals of fish, evidently buried them alive.

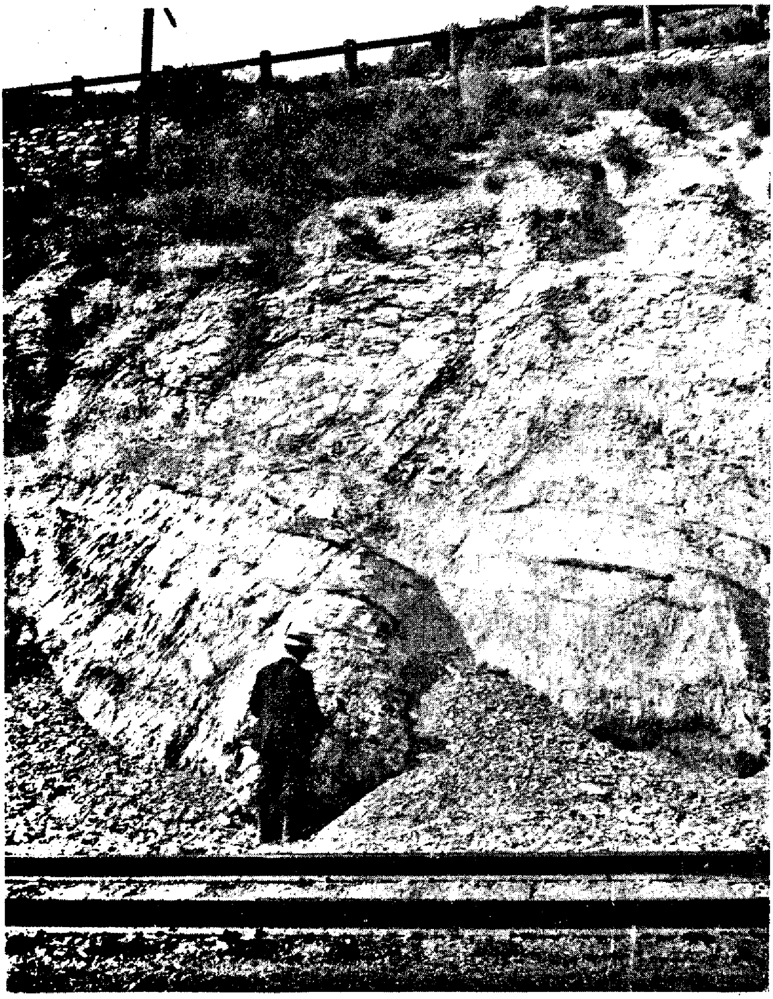

FIG. 119. An exposure of diatomaceous earth, along the main line of the S. P. Railroad, about 2 miles west of Reno, Nevada. (Gale, U. S. G. S.)

find whole square miles of these rocks *crammed full of fishes*, and it is more reasonable to suppose that these fishes contributed the organic materials now forming the oil and gas found in these rocks. It is quite unreasonable to pass over these fish remains, which are here in ample quantity and which were certainly *all buried suddenly* and buried alive, and speak of the slow accumulation of diatoms on the bottom of a stagnant sea where there were neither creatures to eat them nor enough decay to dissipate their putrescible parts.

Phosphates. The minute pelagic gastropods called the *Pteropoda,* which are sometimes known as *sea butterflies,* have also contributed materially to the formation of important rocks. Their shells are *phosphatic;* and although the animals themselves live in the surface waters of the ocean, their shells have in the past accumulated on the bottom, and have become buried as other remains have been, particularly in the Devonian and other rocks. The Middle Ordovician rocks of Tennessee also contain great quantities of these pteropod shells; and when the limestone in which they occur is decomposed into a residual red clay, these pteropod shells remain behind undecomposed, forming the chief part of the residue, which thus becomes a *concentrated phosphate of lime,* and of great value as a fertilizer. Certain kinds of brachiopods also secrete phosphatic shells, and thus have contributed to the production of phosphatic deposits.

Ancient Limestones. Thus we see that there are vast quantities of rocks which have unquestionably been formed by the accumulation of organic materials; and these materials are also of considerable variety. But serious mistakes are liable to grow out of the assumption that *all* limestones, or *all* carboniferous beds (such as graphite), have been formed by organic means. This certainly does not follow; for much of such materials *may have been original or primitive.* Inductive geology *is not a cosmogony;* and no legitimate natural science will undertake to tell how the original materials of the world came into existence.

But the possibility that much of the nonfossiliferous limestone may have been original, or primitive, is constantly ignored in geological discussions. Like the greedy, land-hungry nations, which have parceled out among themselves the unoccupied portions of Africa and Asia, each including within its "sphere of influence" all the unoccupied territory adjacent to its actual holdings, so geologists have long been accustomed to include in their formation-groups all the rocks in sight which are not plainly and positively of different fossiliferous character. It thus comes to pass that large areas and great thicknesses of rocks which contain no fossils have been pressed into the ranks of the Silurian, Carboniferous, or Cretaceous, as the case may be, merely because *no other formation* has yet included them within its sphere of influence, and the other popular hypothesis about the originally igneous condition of the globe forbids the idea of any stratified rocks remaining outside the ranks. But such things only breed confusion; and if we wish to arrive, by any

system of clear thinking, at a true conception of the past condition of our globe, we *must keep the fossiliferous as distinct as possible from the nonfossiliferous or Archæan,* even though the task may be difficult and may involve the possibility of much of the latter being *stratified.* Hence, if we refrain from assuming how our world originated, and refuse to say that a certain limestone is of fossiliferous origin, until we have positive evidence to this effect, the task of explaining the origin of some of these rocks is greatly reduced.

There are doubtless limestones which we can point to as having been formed by growth *in situ* during long periods of time, and which have since been elevated into dry land with little change in position or structure. Such is the case with many of the nummulitic limestones so widely spread through Europe and Asia, and such is probably the case also with many of the Niagara and Onondaga limestones of various parts of America. For instance, in some parts of Wisconsin, the Niagara limestone is thought to have quite distinctly the features of an old coral reef. Some large coral masses "stand erect in the rock, precisely as they grew;" while all around are "accumulations of coral fragments, becoming finer and finer on receding from the reef, and thus the rock graduates into ordinary limestone." (Dana, "Manual," p. 541.)

Similar old coral reefs, or other rocks of natural and slow formation, are found in all quarters of the globe, even in the arctic regions. But though these rocks may be called Ordovician, Carboniferous, or Tertiary, as the case may be, we are not therefore obliged to suppose that any other and older fossiliferous rocks lie *below* their general mass; though, of course, an alternation of strata, or an interfingering of the limestone material with sandstone or shale, may be of common occurrence. Hence, although we may continue to class as Eocene the great nummulitic mountain peaks of the Alps, the Apennines, the Carpathians, and the southern Himalayas, we have no reason to doubt that they often *rest on the Archæan;* and accordingly they may be just as really "old" as the Cambrian limestones of New York or British Columbia. As we shall see in a subsequent chapter, the common method of classifying the rocks off in chronological order because of the fossils which they happen to contain, has no scientific value.

Stratified Limestones. But there are other beds which very manifestly were not produced by growth *in situ* as we find them, or by slow accumulation on the spot in any modern way. These beds also are composed of the remains of corals or crinoids, of

mollusks or brachiopods, of nummulites or other Foraminifera, as the case may be. But they are spread out over much wider areas than any calcareous deposits now forming around our modern coral reefs; they are often composed of *kinds of animals* which in our modern conditions never are disturbed by the slightest movement of wave or ocean current, because of living down in the silent depths of the ocean; yet we find them *constantly interbedded* with deposits so utterly incongruous, so completely foreign to them, as to prove some totally different action of the waters from anything which we have observed to take place within historic times and under scientific observation.

Take for example the following section from the "Lower Barren Coal Measures" of Westmoreland County, Pennsylvania, as given by Dana. The total thickness is 654 feet.

Limestone 6′, shale 10′ (underneath 3′ fire clay and Pittsburg coal)	16′
Coal bed	1′
Shale 10′, *limestone* 3′, shale 25′	38′
Coal	1½′
Shale 35′, Connellsville sandstone 60′ (not persistent), *limestone* 5′	100′
Coal bed	1′
Clay 9′, Morgantown sandstone 50′, *limestone* 4′	63′
Barton coal bed	1′
Shale 100′, *crinoidal limestone* 4′, shale 30′	134′
Coal bed	2′
Shale and sandstone 35′, black *limestone* 4′, shale 60′	99′
Coal bed	1-2′
Shale 30-50′, with Mahoning sandstone (divided sometimes into Upper, Middle, and Lower), with thin layers of shale and *limestone*, and sometimes a thin coal bed, in all 195½′ in Ligonier Valley, varying to 75′ and less elsewhere	75′-195½′

Disregarding the other limestone beds given in this section, we may consider briefly the 4-foot crinoidal limestone between the two thick beds of shale, with coal beds both above and below. *How did it get there?* Almost all our modern crinoids live in the clear depths of the ocean, from 600 feet to over a mile down. At such depths, there are no land sediments now being deposited in our modern seas, or as Dana says, "no means of producing a stratified or bedded structure." It seems self-evident that nothing but a wholly abnormal occurrence, a disturbance of the oceans to their very bottom, is sufficient to explain these conditions.

Yet, in another view of the matter, these things are not abnormal; for they are practically *universal over the earth.* Similar proofs of abnormal conditions of deposit are found, not

only throughout the Carboniferous rocks, but in very many others. Nearly a thousand species of crinoids have been described from the Lower Carboniferous of America alone. But, strangely enough, just because these essentially abnormal conditions are universal, they seem to lose their value as evidence, in the minds of some people, and are looked upon as quite the normal thing.

Professor Suess, in speaking of the limestone formations throughout most of the Alps and Central Europe, says that he had never seen anything in these localities "which could be called a true coral reef." The limestones, he says, "have rather the appearance of thick beds than of true reefs," the corals lying heaped together, with shells, in tuffs or marls, that is, *"always in clastic sediments."* ("Face of the Earth," Vol. 2, pp. 321, 222.)

The same may be said of practically all the limestones of other parts of the world, though occasionally there are localities where the central mass of an old coral reef apparently has remained more or less intact, the fragmental products formed from its destruction having been spread around it for miles on every side.

The Interpretation. It would seem that the most satisfactory explanation of these conditions is to be sought in supposing a disturbance of the oceans to their very depths, perhaps by an *abnormal tidal action,* as will be alluded to later. Indeed, this seems the only way to account for all the conditions as we find them.

Without expanding further on this subject, we may say that all these organically formed materials teach the same lesson; namely, that though the *materials* for these deposits must have been accumulated through long centuries of quiet in the calm, deep waters, yet their *present position and bedded arrangement* indicate that most of them must have been spread out by some great and abnormal action of the waters wholly different from anything which has been known to take place within the historic period.

It would thus appear that we have *two* quite markedly different kinds of deposits now composing our limestones.

The *first* are what we may term normal deposits, formed by long centuries of growth *in situ,* with perhaps only slight disturbance afterwards. These rocks are mostly crystalline, and show little or no trace of their original structure. A large part of the original mass, however, may have vanished, providing the materials of the second class of deposits. Since being thus ac-

cumulated, these ancient coral reefs have been raised high above the sea level by some means, and may now form mountains or table-lands; or they may be now deep down in the earth, over which other and wholly different rocks have been deposited.

The *second* kind of limestones are such as could not possibly have been formed by this normal method of growth on the spot, or could not have been spread out by the ordinary action of the

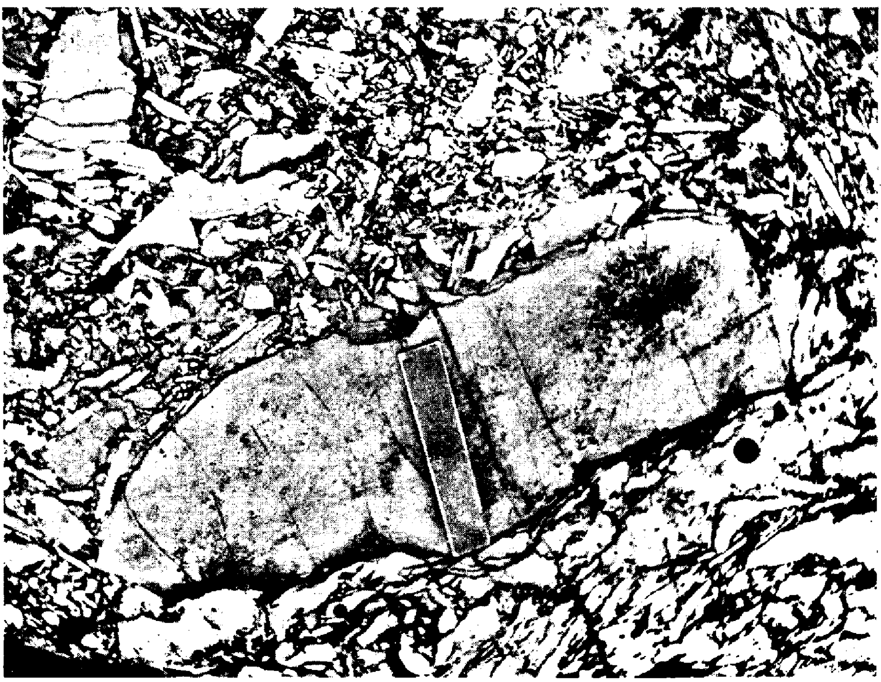

Fig. 120. Brecciated limestone, or limestone conglomerate, from the Calciferous (Cambrian) zone, one mile south of Highgate Falls, Vermont. (Walcott, U. S. G. S.)

waves around the original coral reef. They must have been washed into their present positions by some very abnormal action of the ocean waters. *They are as distinctly sedimentary rocks as sandstones or conglomerates,* though they may be composed of materials which first accumulated in the eternal quiet of the ocean depths, where ordinary stratified deposits are now never formed.

Doubtless it may not always be easy to draw a sharp line of distinction between these two classes of rocks; but until we make this distinction, until we make a persevering attempt thus to classify them, we shall make no real progress in unraveling the records of the past.

At any rate, there is no ambiguity as to the meaning of the numerous limestones known as *"conglomeratic limestones,"* or limestone *breccias.* These rocks consist of "an earthy calcareous matrix, in which flat, pebblelike bits of limestone are irregularly embedded. The pieces are commonly rounded, but sometimes sharply broken; they are fragments of thin limestone sheets, which were broken up, washed, and rearranged during the formation of the stratum in which they occur." (Bailey Willis, "Research in China," Vol. 2, pp. 41, 42.)

But since such beds are usually unbrokenly *conformable* to the beds on which they lie, and since the composition of the matrix and of the contained pebbles *is identical,* with the fossils in each also identical, the interpretation is very plain. Evidently the original bed composing the calcareous materials had begun to harden more or less on the outside or in some of its layers, when it was disturbed and the partially consolidated lime rock was broken, washed, and redeposited after the manner of a conglomerate. But unfortunately, "we do not know the physico-chemical or organic conditions under which limestones consolidate" (*Id.*), and therefore are unable to read more than this outline of the record, so tantalizingly beyond our present knowledge.

Summary. We may sum up the kinds of material furnished by plants and animals somewhat as follows. Plants, including marine plants, furnish:

(*a*) Calcareous materials in minute quantity only, through some calcareous algæ.

(*b*) Siliceous material through diatoms.

(*c*) Carbonaceous materials in immense quantities, which, under certain conditions, may contribute largely to rock formation.

Animals furnish:

(*a*) Calcareous materials in large quantities, through rhizopods, corals, hydrozoans, echinoderms, mollusks, brachiopods, and very sparingly through some of the fishes and other vertebrates.

(*b*) Siliceous materials sparingly through radiolarians and sponges.

(*c*) Carbonaceous materials very sparingly in modern times, but in considerable quantities in former times, as in the case of some of the coals and in many of the oil and gas deposits.

(*d*) Phosphatic materials very sparingly in modern times, and not in any extensive way even in ancient times, chiefly through pteropods and brachiopods.

FIG. 121. Mount Shasta, California, an extinct volcano.

CHAPTER XI

Volcanoes

General Remarks. Volcanoes are mountains which during a period of activity throw out heated rock materials and gases from some region underground. Some of them are low and flat, but most of them rise more or less steeply in a conical mass. They have a pit or basin-shaped depression at the top, known as the *crater,* which is the part whence the eruption proceeds.

Fifty years ago it was confidently thought that the problem of the causes of volcanoes was completely solved. It was so easy to say that they are simply blowholes connected with the earth's molten interior! But the theories then prevalent were based on what was then known of the European volcanoes. Since that time, some of the other great volcanic regions of the world have been studied; and especially has our knowledge of volcanic action been materially modified by a scientific study of such eruptions as have taken place in the Hawaiian Islands, Japan, Martinique, and from Krakatoa, near Java. The results of these studies have compelled a very material modifica-

tion of the older views; and it now seems that many phenomena supposed to be characteristic of all volcanoes, because observed in those of Southern Europe, are not found in all volcanoes in other parts of the globe.

The Two Types. It is now known that most if not all volcanoes have built up their own masses entirely by means of an accumulation of the materials which they have thrown out, such as lava, cinders, and ashes. Some volcanoes emit very little steam or other gases, and their cones are built up almost entirely of lava which they pour out quietly without explosive violence. These are said to be of the *effusive type;* and the volcanoes of Hawaii and Samoa are examples of this type. Their cones are broad and not at all steep. Others, such as Chimborazo and Cotopaxi, blow out immense quantities of steam and other gases with incredible violence, and build steep cones of cinders and scoriæ; and these are called *explosive* volcanoes. Krakatoa blew its volcanic dust from 20 to 25 miles high. In still other volcanoes, there is an alternation in the kinds of ejected materials during successive centuries, or even during the same eruption; so that it is not easy to make a definite classification of all volcanoes on this basis. But in a general way, these two types of volcanoes are recognized.

Size. Although the largest mountain on earth is insignificant as compared with the size of the earth, yet some volcanoes are in and of themselves quite impressive in their proportions.

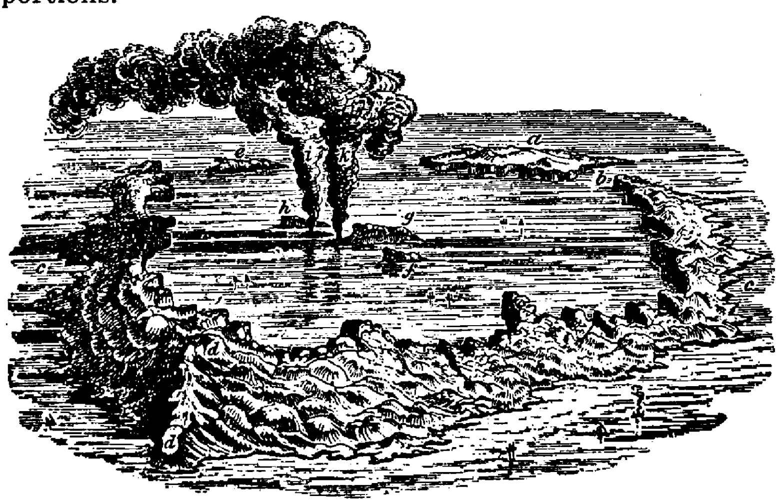

FIG. 122. Bird's-eye view of the Gulf of Santorin, Ægean Sea, during the volcanic eruption of February, 1866. Looking west. The entrance at *b* is 1,068 feet deep, while the peak shown at *d* is Mount St. Elias, and is 1,887 feet high. It is nonvolcanic, being composed of granular limestone and clay slate. (From Lyell.)

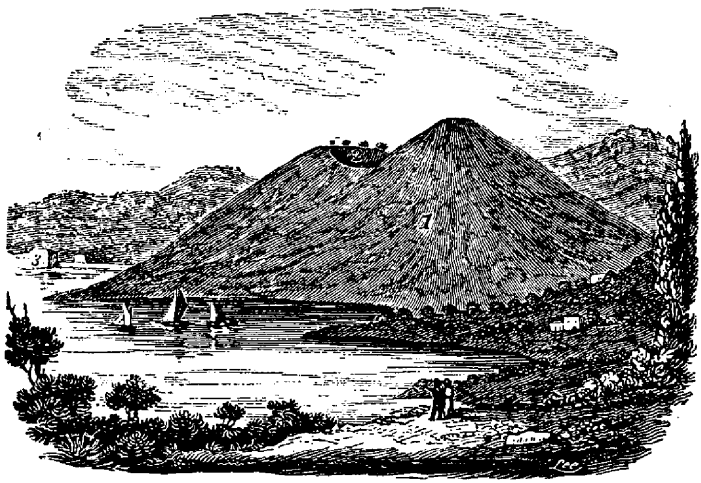

FIG. 123. Monte Nuovo, a new volcano which was formed in the Bay of Baiæ, September 29, 1538. (After Lyell.)

Cotopaxi, in Ecuador, in 19,600 feet high, and has a crater half a mile in diameter and over a quarter of a mile deep. It is still active; but others still higher and only recently extinct are not far away. Aconcagua is 23,000 feet high, Tupungato 21,500, and Chimborazo 20,500. These are some of the highest volcanoes in the world; but as they stand upon a region of country which itself is about two miles above the sea level, their apparent height is not more impressive than many others. Some of those just named have no visible craters, and have not been active for some time.

The Hawaiian volcanoes seem to be low and flat, for they cover immense areas; but in reality, they are about 14,000 feet above the sea level, while instead of rising from an elevated plateau, their bases really rest on the ocean bottom some 14,000 or even 18,000 feet below sea level. Thus their tops are about 30,000 feet above their bases; while as for size, one of them, Mauna Loa, has a crater 3.69 miles long and 1.75 miles wide; and Kilauea, on its eastern flank and only about 20 miles away, has a crater even larger, it being about 8 miles in circumference. The latter is the largest active crater in the world, while Mauna Loa as a whole is the largest volcano in the world, being 75 miles by 50 miles at its base, and 13,675 feet above the sea level (Fig. 124). Indeed, the whole island of Hawaii, which has an area of 4,210 square miles, has been wholly built up by volcanic action, the two mountains mentioned, with a few others, occupying the entire island.

Kilauea is easily accessible, and on this account, is often visited by tourists as well as by scientists. Its crater is a wonderful sight. "Enclosed by a circular wall from 200 to 700 feet in height is a black and slightly undulating plain having an area of 4.14 sq. m., and within this plain is a pit, Halemaumau, of varying area (about 2,000 ft. in diameter in 1905), now full of boiling lava, now empty to a depth of perhaps 1,000 feet. When most active, Halemaumau affords a grand spectacle, especially at night: across the crust run glowing cracks, the crust is then broken into cakes, the cakes plunge beneath, lakes of

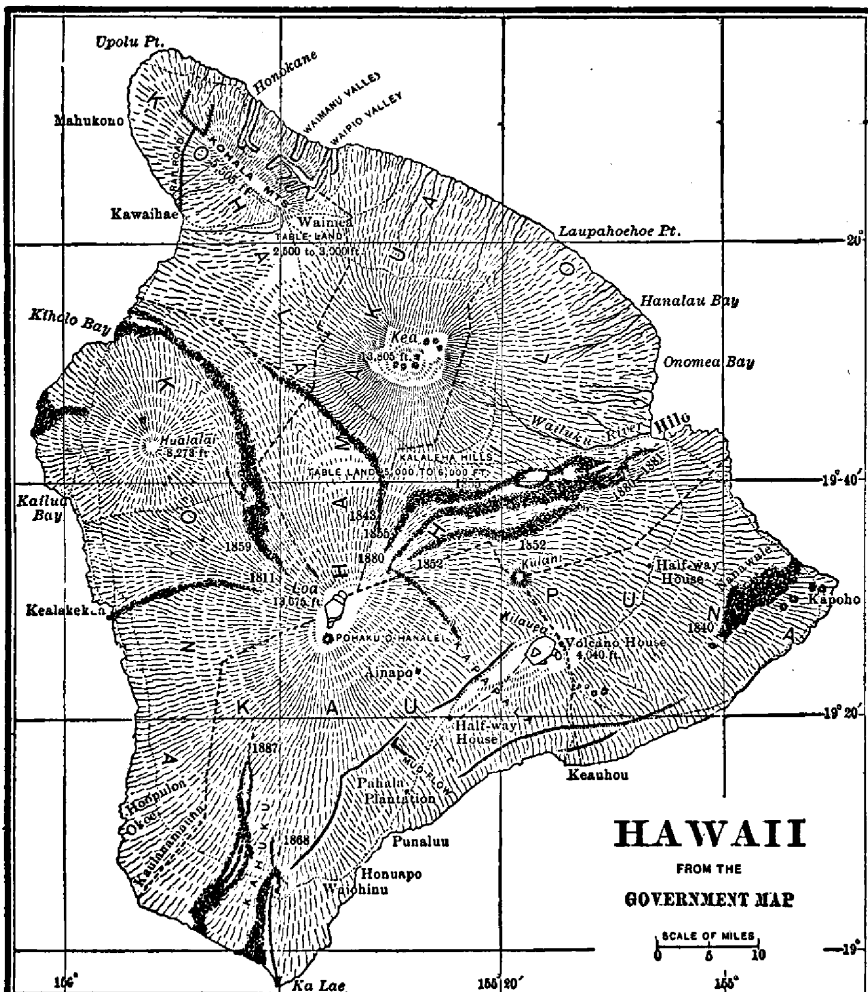

FIG. 124

liquid lava are formed, over whose surface play fire-fountains 10 to 50 feet in height, the surface again solidifies and the process is repeated." ("Encyclopædia Britannica," Vol. 13, p. 83; edition 11.)

Engulfment Craters. Many of the craters of the Hawaiian Islands are of what is called the *"engulfment type"*; that is, they are pit-craters which are enlarged on one or more sides by the breaking off and falling in of their walls, as already described in a small way regarding the inner crater of Kilauea.

FIG. 125. Lava cascades, Kilauea, Hawaii. Such very liquid lavas may sometimes flow at a rate of nearly 10 miles an hour down a slope; and when they cool, they harden into a surface with curved, wrinkled, and twisted, or ropy forms, called by the Hawaiians, *pahoehoe*. (Mendenhall, U. S. G. S.)

Not only so, but the volcanic action on these islands seems to have marched steadily *from west to east*, only the most easterly portion being now active. Thus it would not be impossible to regard the whole chain of these islands as belonging to a more or less connected set of underground phenomena which have been steadily progressing in an easterly direction, the volcanoes to the west having long been extinct.

The eruptions of the mountains just spoken of are always of the quiet or effusive type, and where a portion of the rim does not tumble into the lava and become engulfed, the lava often breaks out through the flanks of the mountain, and sometimes the lava flows occur below the sea level. It is difficult

to regard the seat of such phenomena as situated at any great depth below the surface of the earth.

Explosions. Many volcanoes have appeared *quiescent* for long periods, during which there may have been a gradual accumulation of gaseous pressure inside. Eventually this pressure becomes too great, and an *eruption* begins with an explosion of more or less violence; great quantities of gases, together with dust and blocks of rock, are ejected; and after such an outburst, the pressure inside seems to become relieved, and a

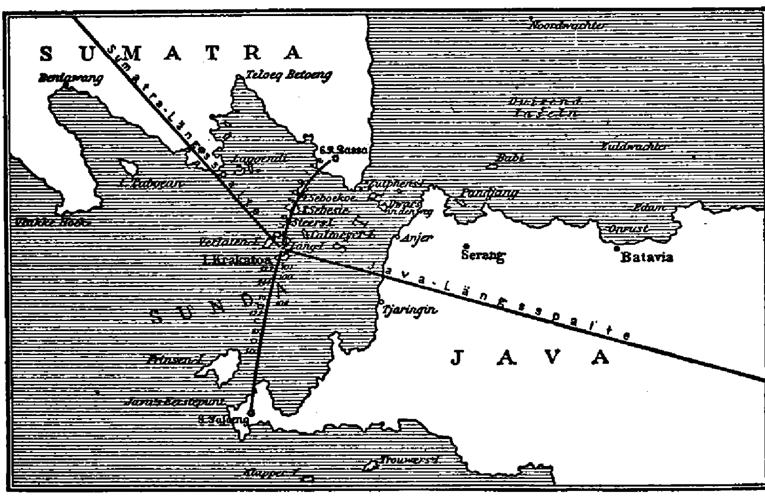

FIG. 126. Map of the Strait of Sunda, East Indies, showing the location of the volcano Krakatoa, the lines being the supposed "rift lines" which center at this point. (From Ratzel.)

quieter outflow of liquid lava succeeds. The most tremendous volcanic explosion of modern times occurred at Krakatoa, a volcanic island in the Strait of Sunda, in August, 1883 (Fig. 126).

"After premonitory outrushes of gas for some time, the great explosions occurred, which blew away over a cubic mile of material from the volcano into the air in the form of dust and ashes. This vast dark cloud is stated to have risen 17 miles into the atmosphere, completely hiding the sun by its denseness over a vast area. The noise of the terrific detonation was heard for more than 150 miles, while the disturbance in the atmosphere was registered by barometers over the whole world. Huge waves, up to 100 feet above high tide, were generated in the sea and rushed along the low-lying coasts of Java and Sumatra, sweeping far inland and destroying towns, villages, and the lives of nearly 40,000 people; they were perceptible 3,000-4,000 miles away."—*Pirsson.*

"Great sea-waves *(tsunamis)* were generated, one of which was estimated to have risen 100 feet, and these destroyed 1,295 towns and villages along the shores, killing 36,380 people. By their force a large ship was

carried inland for a mile and a half and left stranded 30 feet above sea level. Great blocks of stone, weighing from 30 to 50 tons, were also carried inland for two or three miles. All together this was the most stupendous manifestation of volcanic activity known in modern times."— *Grabau, "Textbook," Vol. 1, p. 138.*

In May, 1902, two volcanoes in the West Indies, Pelée on the Island of Martinique, and Soufriere on St. Vincent, blew up, with the very striking peculiarity that the hot gases filled with incandescent particles of rock which they ejected were the most active agents of destruction. These heavy, fiery clouds seemed to act almost like liquids, rolling down the sides of

FIG. 127. The volcanic "spine" of Mount Pelée, Martinique, West Indies. The top of this spine was at this time about 1,200 feet above the old crater rim. It was soon destroyed by the various elements of disintegration. (Photograph by E. O. Hovey, March 25, 1903. Courtesy of American Museum of Natural History, New York City.)

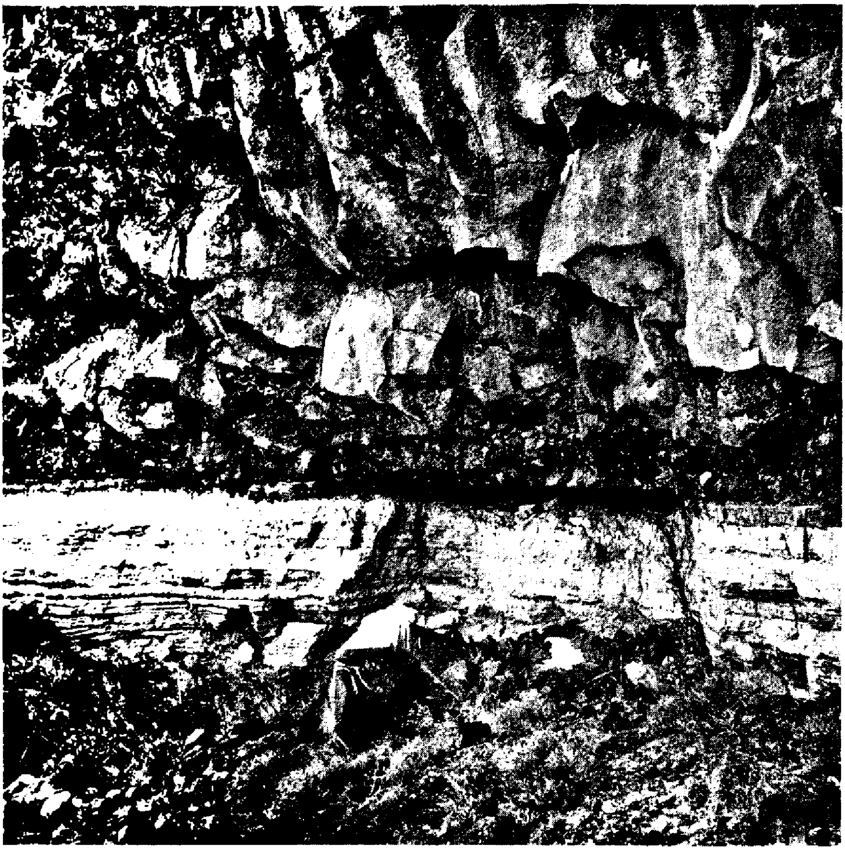

FIG. 128. Layer of basalt about 40 feet thick, resting upon undisturbed lake beds, Cañon Creek Cañon, one mile from Snake River, Idaho. (Russell, U. S. G. S.)

the mountains into the sea, the town of St. Pierre on Martinique being destroyed, with its 30,000 inhabitants. The eruptions of these two mountains did not occur exactly simultaneously, but nearly so. Pelée continued to have explosions of almost equal violence at intervals of only a few weeks for about a year and a half. No lava streams appeared; but the crater became plugged up with a mass of stiff viscous material, which was gradually pushed up as a *spine* or *obelisk* at an average rate of 41 feet a day for some 18 days. The cone in which this spine arose was itself extended upward nearly a quarter of a mile in vertical height, the top of the spine sticking up 1,100 feet above the top of the mountain (Fig. 127). Eventually this spine disintegrated and entirely disappeared. Several ancient examples of somewhat similar volcanic spines are known from various parts of the world.

Magmas. The liquid or semiliquid materials which are found in volcanoes or which are poured out by them are called *magmas.* When these magmas are deeply situated under the earth, and before they are ejected, they seem to contain great quantities of *gases,* especially water vapor, which they apparently hold under this heavy pressure underground in an occluded state or in a state of molten solution. As these masses of molten rock rise nearer to the surface, the pressure is relieved, and the gases tend to escape. This would account for some of the minor phenomena connected with volcanic eruptions; but it seems more than likely that a large influx of water upon a mass of hot magma may be largely responsible for the eruptions of a more violent type.

In composition, volcanic magmas are classified into two types, with all grades intermediate between the two. In one of these, silica and the alkali metal oxides (Na_2O and K_2O) predominate; and on cooling and solidifying, they form what are called *felsites* or *acidic* lavas. The other type contains more lime, with iron and magnesia compounds; and such magmas, on solidifying, form *basalts* or *basic* lavas. The felsites are usually light-colored, from the presence of the quartz; while the basalts are dark or even black, on account of the iron compounds.

The felsites are hard to melt, remaining thick and only semifluid up to a temperature of over 2,000° C., probably because of the large amount of silica which they contain, the silica content running sometimes as high as 75 per cent. Such thick, almost infusible magmas give rise to volcanoes of the explosive type, as the occluded gases have much difficulty in escaping and can do so only with explosive violence. Mount Pelée and other explosive volcanoes exhibit lavas of the felsite type, while Cotopaxi and Krakatao and others have lavas of a kind called *andesite,* intermediate between felsite and basalt. The basaltic magmas are much more easily melted, as they contain only about 50 per cent of silica, and they melt at a temperature as low as 1,300° C. Hence the internal gases can escape from them more readily, without the need of explosive violence. Such are the lavas of the Hawaiian Islands. There are some seeming exceptions to these rules in volcanoes found elsewhere; but such seems to be the best explanation of the differences between the two leading types of volcanoes.

Vapors. The quantities of vapor given off by an active volcano are vast almost beyond comprehension, steam equivalent to 460,000,000 gallons of water having been observed to issue from one of the subsidiary cones of Etna within 100 days, or

4,600,000 gallons of water a day. Even the lavas after being ejected continue to *emit gases for weeks or months while they are cooling.* Hydrochloric acid and hydrofluoric acid have been observed largely in the vents and from the hottest lavas, while free hydrogen is common; and the explosions constantly occurring in the vent are probably due to the combustion of this gas as it comes in contact with the oxygen of the air. Hydrogen sulphide (H_2S) and sulphur dioxide (SO_2) are given off by many volcanoes, but they have not been observed from all. Many other gases are likewise given off, the last to be emitted being *carbon monoxide* and *carbon dioxide,* which are always symptoms of the old age of a volcano, when its activity is about ended and it is partly cooling off. The latter two gases are doubtless derived from the carbonaceous materials, together with the limestone, which have been affected by the underground heat.

Vesicular Structure. The fragmental materials thrown into the air during an explosion are of all degrees of fineness, from dust so minute that it will float for days or months in the upper air, to large rock masses weighing several hundred pounds. All the rock products thrown out by volcanoes, including even the liquid lavas, have a *spongy, vesicular appearance,* due to the presence of gases within them, which tend to expand when the external pressure is relieved. Volcanic rock may almost always be distinguished by this spongy, or vesicular structure, even when in general appearance it may resemble some other kind of rock.

Duration. The length of time during which volcanoes have been active is in some instances quite remarkable. Stromboli, called the "lighthouse of the Mediterranean," has been in almost constant activity for over 2,000 years, and seems to have changed but little in its appearance during that time. For long periods, it seems to be in such a state of balance between its own internal pressure and the external pressure of the atmosphere, "that barometric changes have a marked effect upon its activity, and the Mediterranean sailors make use of it as a weather signal." (Scott.) Etna has had much the same general character and appearance for 2,500 years. Vesuvius, at several times in its history, has been dormant for so long that its sides have been covered with vegetation and with human dwellings, only to blow up again with great violence, destroying many lives.

But entirely new volcanoes have occasionally appeared within modern times. One of the most noted of these occurred in 1831, in the Mediterranean, between Sicily and the coast of Africa. A cinder cone was thrown up from the sea, discharg-

ing much gas and scoriæ or fragments, the cone finally attaining a height of over 200 feet above the sea, and a circumference of 3 miles. The water at this point was about 800 feet deep, so that measured from the sea bottom, this mountain attained a height of 1,000 feet. But when the eruption ceased, the waves soon demolished it, leaving only a shoal to mark its site. (Geikie.) Even this shoal seems now to have disappeared. Several other submarine volcanoes have appeared from time to

FIG. 129. Mount Lassen, the only active volcano in the United States. (Photograph by Loomis.)

time, in the Azores, also near Alaska, and one even off the west coast of Ireland, in 1783. In September, 1759, a new volcano burst forth in Jorullo, in Mexico, in the midst of a cultivated plain. It is now nearly a mile high. A similar one appeared in Salvador, in 1770, and is now some 6,000 feet high. Mount Lassen, in Northern California, is the only active volcano within the limits of the United States proper. It began to erupt in 1914, after an indefinite period of quiescence (Fig. 129).

Other Phenomena. Heavy downpours of rain, accompanied by marked electrical and magnetic disturbances, often accompany volcanic eruptions. They were especially noted in connection with the eruption of Mount Pelée, in 1902. The electrical discharges are partly accounted for by the fact that the vapors have been observed to carry a positive charge, and the cinders a negative.

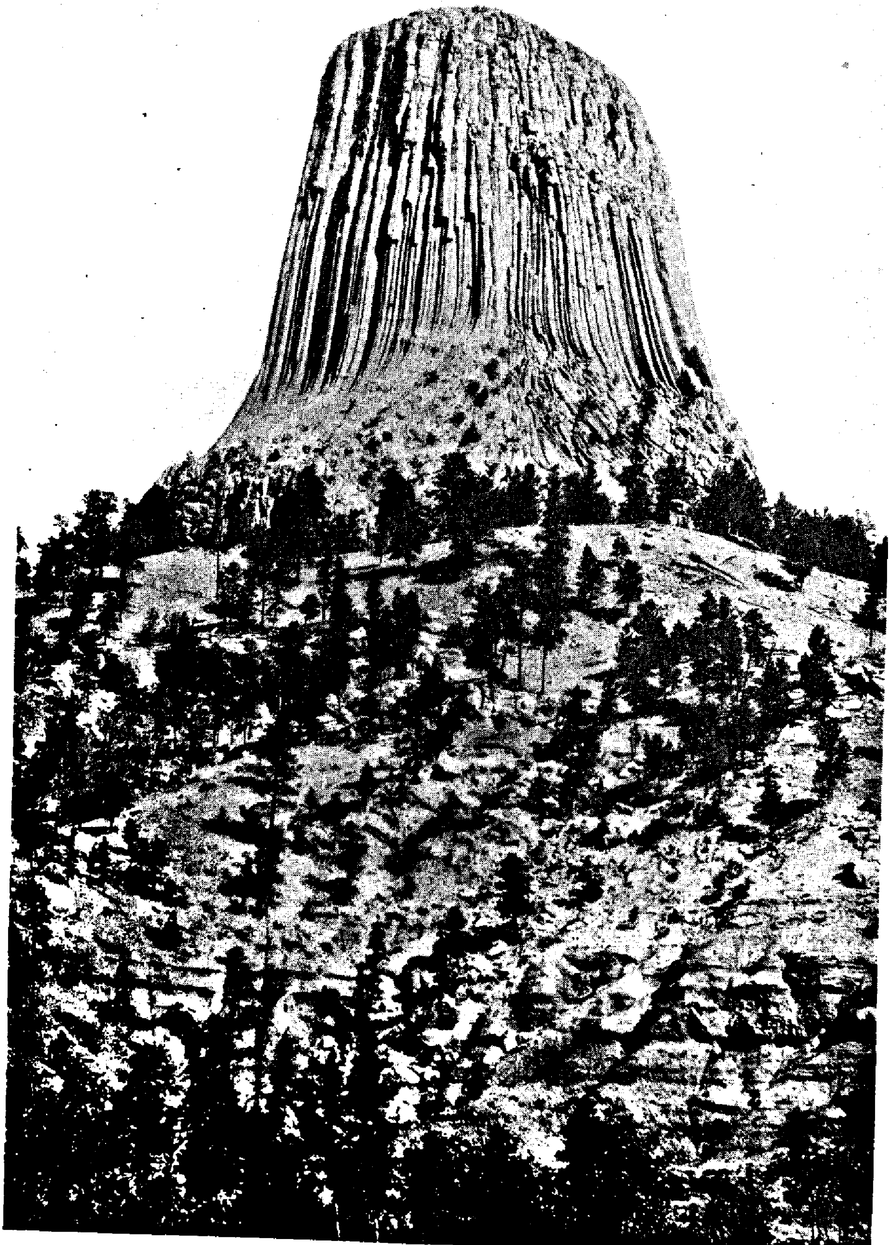

FIG. 130. "The Devil's Tower," Crook County, Wyoming. This is regarded as a laccolithic monument, the former covering being supposed to have been eroded away. It may have been the neck or plug of an old volcano. (Darton, U. S. G. S.)

Extinct volcanoes are found in all parts of the world, great numbers of badly eroded volcanic *necks* or *plugs*, often with radiating dikes, like the spokes of a cart wheel, showing where they once were. The Rocky Mountains contain many such wrecks of former volcanoes; but almost every corner of the globe, including many regions where no volcanic activity has been seen within historic times, shows signs of former action. Many such relics of old volcanoes are to be seen in the New England States and in Eastern Canada, in the British Isles, in France and Germany, and, indeed, in many regions where the thought of volcanic activity seems almost as strange as that of snow in the tropics.

Location. The location of volcanoes is thought by some to be an important point in considering the causes of their phenomena. If the great mountain ranges have been formed by the crumpling up and folding of a thin crust of strata resting on a molten mass beneath, we should most naturally look for volcanoes along these lines of folding; for on the old view, volcanoes were supposed to connect directly with this molten interior. But this is exactly where we do *not* find them, but rather on the flanks of the main chains, as in the Andes, or on the low grounds near their bases, or even far away from any mountain range. Neither is there any great line of earth fissure connecting neighboring volcanoes, as some have supposed; for as the result of investigations on this point carried on in Italy, it seems that no such traces along a line of earth fissure connecting the various volcanoes can be made out. (A. Geikie, *Nature*, May 30, 1901, pp. 103-106.)

Another interesting fact in this connection is the remarkable way in which volcanic outbreaks have occurred near the Grand Cañon of the Colorado. This cañon is an opening about a mile deep through all the stratified deposits down to the granite. Yet numerous volcanoes have broken out *upon the very rim of this cañon,* instead of breaking out at its bottom; and the lavas of these outbreaks have overflowed the rim and descended into the cañon, largely covering parts of its sides, thus proving that they were formed *after* the cañon itself had been made. In connection with such facts as this, it is impossible to think that these volcanic vents are connected with any very deep-seated part of the earth's interior.

"The old idea that the earth has a hot, liquid interior, and that the downward pressure of the contracting cold and solid lithosphere forces this liquid out, and thus gives rise to volcanoes, has been completely disproved by a number of considerations, and is no longer held. The independent

eruptions of adjacent volcanoes in the same group, and the fact that the lava column in Mauna Loa stands 10,000 feet higher than that in Kilauea, only 20 miles away, are disproofs of this view."— *Pirsson.*

Two volcanoes not far apart may simultaneously throw out lavas of very different composition. Two in the Lipari Islands may be given as examples, for the lava of Stromboli is basic or

FIG. 131. Mammoth Hot Springs, Yellowstone National Park, Wyoming. (Jackson, U. S. G. S.)

basaltic, while that of Vulcano is highly acidic or felsitic. Many similar examples might be cited. If these lavas were coming from a common source, the great hypothetical molten interior, it would be much like getting salt water and fresh from separate faucets on the same pipe.

Causes. As the result of very much discussion of the subject during recent years, it seems certain that, whatever may be the initial cause of the heat itself, the reservoirs supplying the magmas exist as pockets in comparatively shallow portions

of the crust only a mile or two down, as Dutton has shown.[1] The direct cause of an eruption seems to be, in some cases, the obstruction of the usual outlet for the vapors which are constantly being produced, and in other instances, the sudden influx of a large quantity of water upon the fiery mass of superheated rocks. In either of these instances, there would be necessarily a violent bursting forth of the imprisoned vapors whenever they finally attained enough pressure to lift the overlying rocks.

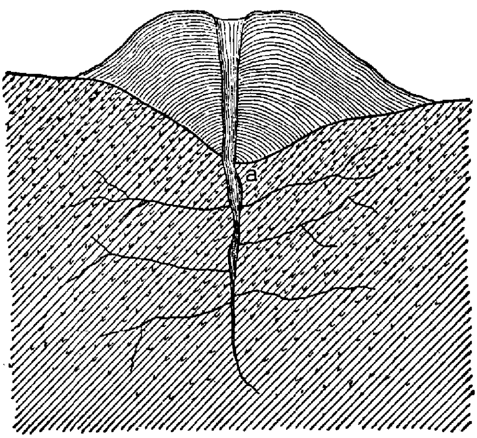

FIG. 132. Diagram to illustrate the conditions necessary for geyser action. The temperature of the water increases with the depth; and whenever the steam pressure in the lower levels is great enough to lift the overlying mass of water, there is an eruption. (From "The New International Encyclopædia," by permission.)

As for the ultimate source of the heat itself, this will be more properly left over for another chapter.

Hot Springs. Long after a volcano has ceased to explode or to throw out molten lava, *vapors and gases* continue to issue from its flanks, or from various fissures in the surrounding country, perhaps many miles away. Even the beds of lava themselves may continue to exhale steam and other gases for many years after they have been deposited. These may give rise to *fumaroles,* when steam and other vapors, such as HCl and H_2S, are given off; while if sulphurous vapors are prominent, these vents may be called *solfataras.* It seems that the hottest fumaroles give out acidic gases, while the cooler ones are more inclined to produce carbon dioxide. Any of these substances may become dissolved in streams of underground water, producing various kinds of *mineral springs;* or, if the water continues to hold its heat until it finds its way to the surface, it will issue as a hot spring or even as a *geyser.*

Such hot springs are common in different parts of the world, as in the Yellowstone Park, near Mount Shasta, and near St. Helena, California, also in Iceland and New Zealand, which

[1] Major Dutton tells us that there is a growing mass of strong and highly concordant evidence to the effect that the seat of the reservoir of a volcano "is very shallow and seldom more than three miles deep. Very rarely is there any indication of its being more than two and one half miles deep, and it is certain that in many cases the depth is less than one mile. The indications are that most of the volcanic eruptions originate at depths between one mile and two and one half miles."—*"Journal of Geology," May-June, 1906.*

are all scenes of former volcanic activity. All the active or recently active volcanoes have many such fumaroles and hot springs in their vicinity.

Former Activity. Considering the world as a whole, there are probably three or four times as many extinct volcanoes as active ones. This would seem to indicate that there was probably a period of intense volcanic activity in the long ago, soon after the earth took its present form of land and water distribution. Volcanic activity is undoubtedly dying out in point of geographical extent, though possibly increasing in violence in some particular localities.

Dating. The dating of volcanoes and of past volcanic upheavals is subject to all the infirmities of the artificial geological chronology now prevailing, being based on the alleged age of the accompanying strata either below or above, or both. Such alleged dating of the beginnings of volcanoes, or of ancient outflows of lavas, has no scientific value.

CHAPTER XII

Heat: Its Effects and Its Causes

Quantity of Erupted Materials. It is important for us to have some adequate idea of the vast *quantity* of material brought up from underground and deposited by the various kinds of volcanic activity. For instance, there are some 107 volcanoes in Iceland, "with thousands of craters great and small." (Thoroddsen.) Yet in *one single outflow*, there issued from the craters of Laki, at Skapta, in 1783, materials which now cover an area of 218 square miles, and which would make a cube 7.5 miles on each side, or a total of over 400 cubic miles of rock. The largest unbroken lava field in Iceland covers an area of 1,700 square miles, and has been estimated to be sufficient to form a cube 13.4 miles on a side. One single stream of lava is 60 miles long. With all this vast quantity of material brought up and spread out over the top of the ground, it is no wonder that "there are gigantic fissures, running for several miles, caused by subsidences of the underlying sections." (Thoroddsen.) The fragmental materials blown out by the great explosion of Krakatoa, in 1883, were estimated at 4.3 cubic miles.

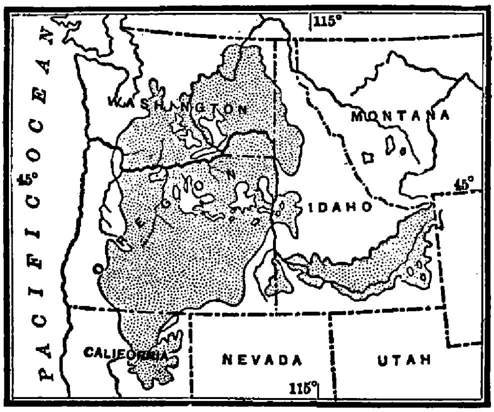

FIG. 133. Map of the region around the Columbia and Snake rivers, showing the lava fields. (After Bowman.)

Still more gigantic are the outflows of lava which in prehistoric times have covered great areas near the Columbia and Snake rivers, in the extreme northwest of the United States. It seems uncertain whether these outflows occurred from mere open fissures, or from a large number of craters which are now concealed and the products of which have become blended to-

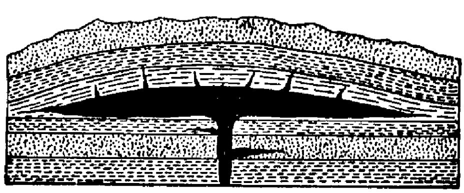
FIG. 134. Section of a laccolith. The black area indicates the igneous rock. (From "The New International Encyclopædia," by permission.)

gether to form great continuous sheets. The view at present held by those who have made the most careful study of the conditions is that *a large number of low, broad craters* were the real origin of these lava sheets, the lava being of an extremely liquid character, spreading out in streams some of which were 50 miles long and many miles wide. All together, these volcanic outflows in this part of the United States are estimated to cover from 150,000 to 200,000 square miles of area, and to be in places 3,000 feet deep. In the Deccan, Western India, are

FIG. 135. Intrusive sheets of igneous rock, Cottonwood Cañon, New Mexico. (Lee, U. S. G. S.)

similar sheets of trap which have been explained as due to great fissures, but which on further examination will probably be found to be due to numerous low, broad volcanic vents, such as are now assigned as the cause of those sheets on the Columbia and Snake rivers. Large areas in the north of the British Isles, in Scandinavia, and in many other parts of the world are also covered with volcanic outflows which took place long before the beginnings of scientific observation, and yet since the stratified rocks were formed, for these volcanic sheets now lie on top of the stratified beds.

Definitions. In other instances, however, sheets of melted rock have been spread out over stratified beds while the latter were still under water, and other strata were subsequently laid down upon the lava. In still other cases, the lava seems to have intruded itself between the layers of sedimentary rock after both the upper and the lower beds had been formed. Such

lavas are called *intrusives;* and they are thought to be of common occurrence. When a quantity of lava fills a fissure and solidifies, it is called a *dike* (Fig. 136); and as might be supposed, such a dike will be found cutting across the bedding, if the country rock around it is stratified. Lyell observed a fissure 12 miles long near Etna which was filled with liquid lava not yet solidified. *Necks* are solid plugs of lava filling old volcanic vents. Various other names are applied to the many peculiar forms in which consolidated lava is found. A great mass of granite or other so-called *Plutonic* or *igneous* rock, perhaps many miles or even hundreds of miles in extent, which, as in the cores of most mountains, seems to become wider the deeper it is traced down into the earth, is termed a *batholith.* The great central part of such mountains as the Rockies and the Sierra Nevadas is spoken of as batholitic; but such a name ought not to carry any implication of the theory that these masses came up from below or that they are in any way connected with the fabled liquid interior of the earth. A small batholith is termed a *stock* or *boss.* Granite, diorite, and gabbro are the frequent constituents of bosses and batholiths, and the texture of the rock usually becomes progressively coarser as we proceed from the edge toward the center of the mass, the interior having cooled more slowly than the outside, this slower cooling having resulted in a coarser grain, just as it does when sugar cools, or when salt crystallizes from solution; for the slower these processes proceed, the coarser is the resulting grain of the material.

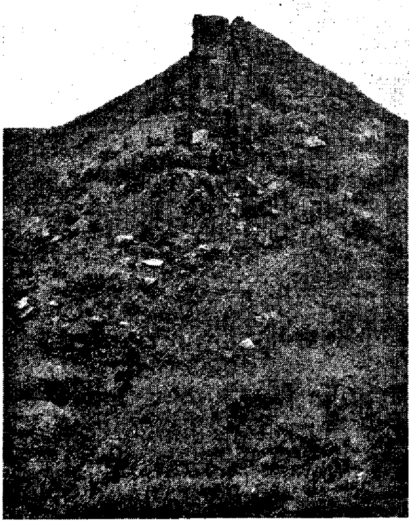

FIG. 136. Lamprophyre (mica-trap) dike, 15 feet thick, about 6 miles east of Big Sandy, Montana. The dike is harder than the country rock. (Pepperberg, U. S. G. S.)

Metamorphism. The term *metamorphism* is applied to any profound change of structure or character which a rock undergoes, except disintegration. Generally metamorphism results in the rock's becoming harder and more crystalline, and often in

its showing an entirely different set of minerals within it, these minerals being produced by the chemical changes and combinations which accompanied the metamorphism. Any degree of change may be produced, from the mere solidification of loose sediments to the most profound transformation, and there are all grades between the two extremes. Sedimentary or stratified beds are not the only rocks which may become metamorphosed; igneous rocks are also frequently changed by metamorphism, and when the process is at all complete, it is quite impossible to tell the original character of the rock. This is only natural; because a clay shale, a volcanic tuff, or a basalt may contain the same chemical elements in much the same proportions, and similar conditions of heat, moisture, and pressure may convert any of them into the same kind of metamorphic rock.

A lava flow on the surface or in a fissure near the surface will ordinarily effect some metamorphism of the rocks with which it comes in contact. Bituminous coal may lose its volatile constituents and become like coke; clay may become baked to the appearance of red brick or rough earthenware; or limestone may lose much or all of its carbon dioxide and be changed into quicklime. But such changes are not very marked, and are the result chiefly of what may be termed *dry heat,* without the added assistance of the other factors of change which often accompany igneous intrusions that take place deep underground. The latter usually are already at a much higher temperature than the surface lavas, they retain their heat much longer, and the hot vapors and gases which they contain in far greater abundance have a more profound effect upon the rocks around them.

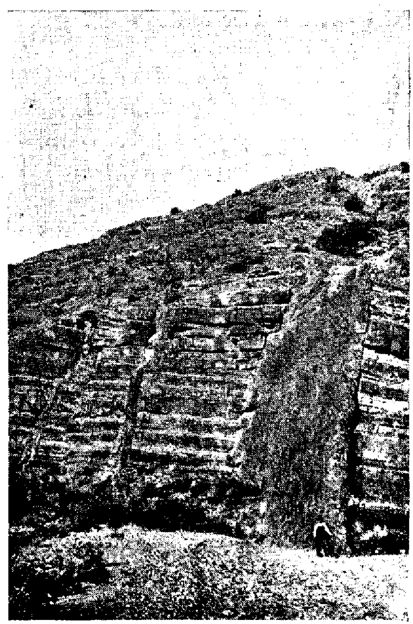

FIG. 137. Diabase dikes in Red Beds (Triassic), on Alamillo Creek, New Mexico. (Darton, U. S. G. S.)

Magmas which contain large amounts of vapors or gases (called *mineralizers*) are much more effective in bringing about a metamorphism of the surrounding rocks than those magmas which do not contain them. Hence *acidic* magmas are more

efficient than *basic* magmas. If the invaded rock contains considerable quantities of lime or alumina, it is much more likely to become changed in character than if it is composed largely of silica.

We usually find a gradual change in the surrounding rock; that portion nearest to the invading magma is most altered, while that which is farther away is less changed. The part of the invaded rock in immediate contact with the igneous magma may be so transformed that even the microscope will scarcely distinguish the sedimentary material from the intruding magma. Farther away, conglomerates or sandstones may become quartzites, clay may change into slate or mica schist, limestone may become marble, bituminous coal may be changed into anthracite or graphite, and limonite may become magnetite. The interstices between the particles of the invaded rock may become filled with iron oxides, quartz, feldspar, mica, or other minerals, thus cementing the original grains together with a firm matrix.

All such phenomena come under the head of *contact metamorphism,* or *local metamorphism;* but the results of such work may often transform large areas of sedimentary rocks, because of the widely branching streams of igneous intrusions, and because the superheated mineralizing waters seem to dissolve many very diverse kinds of rock and to carry these solutions considerable distances, only to deposit them again in some other form scarcely recognizable as having the same origin as the original deposit.

The term *regional* or *dynamic metamorphism* is applied to a still more widespread transformation of the rocks, often affecting hundreds or thousands of square miles. Usually such rocks are wholly crystalline and have lost all traces of whatever stratification or fossils they may have possessed originally.

Many metamorphic rocks show a tendency to break or split in some directions more easily than in others. Such a tendency is termed *cleavage;* and to distinguish this kind of cleavage from that shown by minerals, it is commonly called *slaty cleavage.* Roofing slate is a good example of a rock exhibiting such a tendency to split or cleave along definite surfaces. This structure is not at all like the stratification planes formed by sedimentation, and often develops in rocks approximately at right angles to the stratification planes which were originally present. It may have been developed by the stresses of lateral compression; but geologists are not agreed as to its exact cause.

Schistosity or *foliation* is seen in certain metamorphosed rocks with a banded appearance, where the component minerals

form nearly parallel surfaces, along which they more readily divide or split.

Causes of Underground Heat

History. The ultimate source or sources of the heat manifested in all parts of the earth, has been the occasion of much discussion. In the earlier days of the science of geology, it was considered a sufficient explanation to say that the earth was originally a fiery, liquid mass, and that the interior is still in this condition, not having yet cooled off. On this basis, volcanoes were simply the vents or blowholes from this liquid interior; the mountains were the puckers forced up by lateral compression caused by the contraction of the surface or cooled part, as the rest gradually lost more and more of its heat; and metamorphic rock was easily explained as merely rock which had come into more or less intimate contact with heated rocks from this molten interior.

But presently physicists and astronomers pointed out that the earth behaves as an extremely *rigid* body in resisting the deformative tendencies exerted by the sun and the moon; for if the earth were not more rigid than the best steel, it would show tides in its surface. The fact that it shows tides in its superficial watery envelope, but not in its rocks, is the best of proof that its interior can not be in the liquid or semiliquid condition indicated by this theory. Next it was pointed out that a column of lava could not find its way up through a cool crust of even moderate thickness without losing so much of its original heat as to *solidify before reaching the surface.* And if this would be the case with even the largest of volcanic craters, what about the *dikes* of melted rock, which in many cases are only a few feet in thickness? Furthermore, it was pointed out that, if the mountain ranges were due to the contraction of a crust even 25 or 50 miles thick, these mountains would be of *much greater breadth,* if not of greater height; "for if a solid plate of any kind be broken and the fractured edges be turned up by reciprocal pressure in presence of a resisting body beneath, the width of the protruding mass will bear a definite relation to the thickness of the plate." (Prestwich.)

We have already seen that this old idea that the earth has a hot, liquid interior, the contracting of the crust over this molten interior being the cause of the lava outflow and of all the other related phenomena, "has been completely disproved by a number of considerations, and is no longer held." (Pirsson.) We may therefore discard all such theories based on the nebular

hypothesis, and see if we can not establish present, commonplace causes competent to act as sources of heat in producing rock metamorphism and volcanic phenomena. The numerous speculations which have prevailed regarding the present condition of the earth's interior, all based on some form of the theory that the earth is a cooling globe, have no scientific value, and are a hindrance to scientific progress. It is much to be hoped that the time is not far distant when this assumption of a cooling globe will become an anachronism in any treatise on geology.

Sources of Heat

Five Sources. We may distinguish *two* very slight but nevertheless universal sources of change in the rock, capable of producing induration, perhaps metamorphism; and *four* more positive sources of heat of various degrees. We give them here in what may be considered the reverse order of their importance as means of rock change, though this is almost the direct order of their universality:

1. Changes in atmospheric pressure.
2. The effects of tidal action.
3. Chemical action.
4. Radioactivity.
5. The mechanical movements attending mountain making.
6. The burning of coal and oil beds, with accompanying chemical action.

Of these, only the *third, fourth,* and *fifth* are now generally recognized in geological literature. The last (6) is sometimes alluded to, though in a very fragmentary way; while the first two have only a few scattering references here and there.

Changes in Atmospheric Pressure. In a paper read before the British Association at Glasgow, F. M. Denison reported that the depression of the earth's crust due to an area of high barometric pressure can be detected by a seismograph at great distances from the center of the depression, and that the approach of a barometric depression is indicated by the seismograph long before the barometer shows any sign of it. (*Nature,* October 10, 1901, p. 587.)

The effects of varying degrees of atmospheric pressure are incidentally referred to by G. K. Gilbert in his presidential address before the American Association (*Science,* January 22, 1909, p. 131); and it would appear that this cause, so universal and ceaseless in its action, must, in thousands of years, result in considerable changes in the texture of rocks.

Effects of Tidal Strain. The Tidal Committee of the British Association, August, 1871, while confirming the previous announcement of Professor William Thomson (Lord Kelvin) about the earth's being "more rigid than steel," admit that the superficial parts must yield in at least some degree to the tide-generating influences of the sun and moon. Theoretically we know this must be so; and it is difficult to see how a variation of stress of this kind can thus be *repeated twice every twenty-four hours* for long ages upon all rocks of our globe, without producing enormous effects in the way of structural change or metamorphism.

Chemical Action. The oxidation of ores containing sulphur, such as pyrite and marcasite, is too well recognized as the source of heat in many mines, and as a source of the heat of many hot springs, to need any further mention here. As Dana has remarked, these facts throw a cloud of doubt over the real value of observations made regarding the increase of heat with descent downward in the earth, and this chemical action "has always to be considered in such investigations." ("Manual," p. 257.) Years ago, Sir Humphry Davy, and later, Gay-Lussac, French chemist and physicist, made chemical reaction in the earth's interior the foundation of their theories of volcanic action; and these chemical explanations of volcanic heat were for a while quite popular. Even Sir Charles Lyell at one time seemed to think them sufficient to account for the phenomena.

Radioactivity. Since the discovery of the radioactive properties of matter, these properties have been appealed to as a source of heat. That a part of the earth's interior heat may be due to this cause seems reasonable; while some enthusiastic students of the subject have thought that this might serve as an explanation for all these phenomena. Investigation seems to show that radium, with its heat-generating influences, is probably confined to a comparatively shallow zone on the outside of the earth, extending downward only a few miles. It is also known that the radioactive substances are widely scattered through the rocks, and especially through the igneous ones. But as to the significance of radioactivity in general, "there is wide diversity of opinion on the subject, and, at present, this view has not advanced beyond the speculative stage." (Pirsson, "Textbook of Geology," 1920, p. 223.)

The Friction Attending Mountain Making. The enormous effects which the mechanical movements attending mountain making are capable of producing, no matter what we may con-

sider the ultimate cause of these latter processes, have long been recognized and need not long detain us. These effects may be illustrated on a small scale by what takes place in mines when the pressure crushes the pillars and forces the strata out of position in what the miners call *creeps*. Prestwich records one case where, when the pressure began to crush the pillars, the heat which was developed was so great that the observer "feared it would set fire to the coal." ("Controverted Questions," p.

FIG. 138. Hillside creep of surface strata. The railroad is badly out of line. On a tributary of the Yukon, at Coal Creek, Alaska. (Atwood, U. S. G. S.)

192.) In some mountain regions — for instance, Aspen, Colorado — there sometimes appears to be a general slipping of a whole mountain side in the vicinity of old faults; and in the course of a few years, surveys are found to be several feet out of line. (*Mines and Minerals*, March, 1902, p. 342.) It seems to be generally admitted that in the crushing of a rigid material, such as rock, *almost the entire mechanical work is transformed into heat;* and hence if "the disturbance affecting the massive strata of a great mountain range were abrupt, an intense degree of heat might be developed" ("Controverted Questions," pp. 235, 236); Mallet contending that "7,200 cubic miles of crushed

rock would cause heat enough to make all the volcanic mountains on the globe" (Dana).

While all mountain making may not have been of this abrupt and violent character, numerous ones of the great breaks and faults in the rocks are conclusive proof that tremendous convulsions of a violent character have many times taken place in the long ago; and it is always well to remember the possibilities in this respect. Many of the enormous outflows of trap and basalt which have occurred in the remote past suggest this as their cause by their proximity to greatly disturbed regions, and are in many cases easily separable, by their compact structure, from the true lavas of volcanoes.

Combustion of Coal in Mines

General Remarks. But we have another and very potent cause of underground heat in the oxidation of vast carboniferous deposits, such as coal and oil. This was commonly taught a hundred years ago as the source of volcanic heat; but the empirical investigation of this subject has been neglected for nearly a century. On this account, it may be proper to enter into the subject at considerable length, though we have space for only a few of the facts now available as illustrative of this subject.

As is well known, fires frequently take place in coal mines, and these, with the resulting explosions of coal dust and gas, often cause terrible destruction of lives and property. But it is not so generally known that these fires frequently get beyond the control of the mine owners, and burn for long series of years. In Nova Scotia there are several instances of such fires' having been burning for twenty or thirty years; and at the last accounts available, some were still burning there. In the anthracite region of Pennsylvania also, we have some instructive examples of how persistently coal seams will burn when once ignited.

Various mines in Pennsylvania have taken fire and have burned for considerable periods of time. Notable among these is the Summit Hill mine, which at the present writing (1923) has been burning for over sixty years, in spite of the utmost efforts of the owners and the expenditure of over three millions of dollars to put out the fire. The area involved is about a mile long and 1,500 feet wide, and the coal seam in which the fire is situated is some 50 feet thick and consists of solid anthracite, with several hundred feet of rock above it.

Observations at this place, as well as many taken elsewhere, prove that the combustion of the coal is not at all dependent upon the oxygen of the air, but that the requisite oxygen is extracted from the oxides in the adjacent rocks, by a chemical

process. This being the case, such fires might burn to any depth whatever; and, of course, at a much greater depth than that of the Summit Hill mine, much more of the heat generated would be conserved, and this would contribute to the production of phenomena still more resembling a true volcano. But even here it does no require much imagination to transform this quarter mile of incandescent rock into a baby volcano.

Amount of Coal. The coal beds of this part of Pennsylvania seem to average about 75 feet in thickness of actual coal, mak-

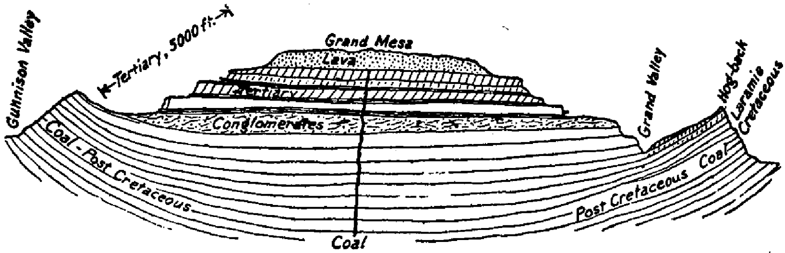

FIG. 139. Diagram of the Grand Mesa, Colorado, showing how lava beds have originated from burning coal beds.

ing a total of about 150,000 tons to the acre, or about 96,000,000 tons to the square mile. The anthracite areas are usually divided into four fields:

1. The Northern coal field, in one great basin 55 miles long and from 2 to 6 miles wide.

2. The Eastern Middle field, containing about 33 square miles.

3. The Western Middle field, some 37 miles long, with a maximum width of about 5 miles, and containing over 90 square miles.

4. The great Southern field, some 70 miles long, and covering an area of 180 square miles.

The total production from this region up to 1893 was about 902,000,000 tons, with about 17,245,000,000 tons still in the ground. It would thus seem that we have here enough latent energy to keep a dozen volcanoes steaming away for a long time, especially if it were supplemented by a fair proportion of limestone and an occasional supply of underground water; for there would be about 1,500,000,000 tons for *each* of them to work upon.

Other Examples. The lignite coals bordering the Mackenzie River have been burning continuously ever since first seen by Sir Alexander Mackenzie in 1789. On the Little Missouri River is a region 200 miles long by 30 miles wide which was burned out in prehistoric times, some of the overlying rocks having

been baked to a "half-fused cellular or scoriaceous and pumice-like character, looking like the products of a volcano." (Dana, "Manual," pp. 266, 267.) But in these cases, the burning beds were far too shallowly situated and were much too thin themselves to produce the phenomena of a volcano.

In the vicinity of New Castle, Colorado, are other burning coal beds, which have evidently been burning for hundreds or perhaps thousands of years, with much more resemblance to the characteristics of a real volcano. These beds form a large synclinal basin some 50 miles from the northeast outcrop to the

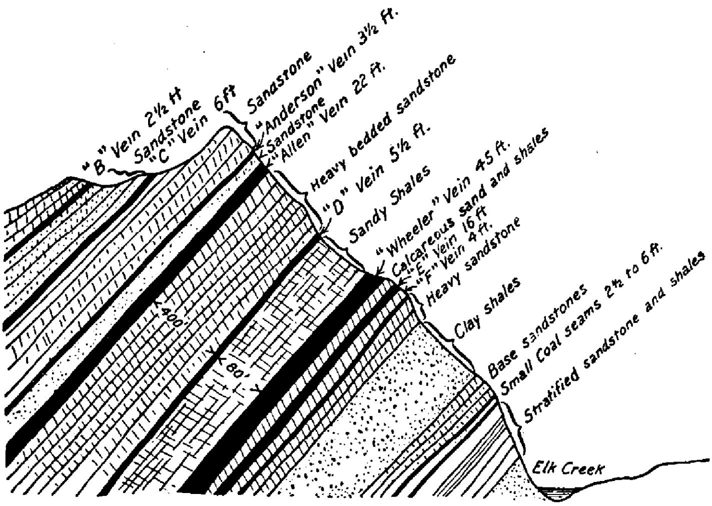

FIG. 140. Diagram of coal beds at New Castle, Colorado.

southwest outcrop, the high mesas between these outcrops being largely covered with sheets of basaltic lava which has undoubtedly come up through vents or fissures from the burning beds below. Several small volcanoes near by have doubtless been produced in much the same way, the Dotsero Volcano and the one near Basalt, on the Colorado Midland Railway, being examples.

Mr. P. C. Coryell, of New Castle, Colorado, in a letter to the present writer, says:

"I have particularly observed that no lava has come out of any of the profound faults which doubtless extend to tremendous depths under the Triassic measures [in this locality]; but that the origin of the lava is invariably the least disturbed portions of the sedimentary beds, but usually within a mile or two of some great fault or crack.

"It may be reasonable to suggest that owing to the pyritiferous condition (locally) of the Triassic sandstone, and the close proximity of large

bodies of gypsum, a chemical action between the iron, sulphur, and gypsum was set up in the process of faulting, which developed what we call a volcano."

This gentleman goes on to say: "All true volcanoes are undoubtedly located in stratified rocks, and may not be confined to any given formation. In refutation of the theory that volcanoes are the chimneys connected with the fluid center of the earth, I will mention that, at this point in Colorado, nearly every system except the Triassic is represented on a tremendous scale. . . . Yet most of the lava flows have broken out on top of the Tertiary formation, being the most extreme point possible from the granite. The volcanic districts in tropical countries are only doing to-day what this district has gone through from one to five thousand years ago; and doubtless their volcanoes have no more connection with the central portion of the earth than our extinct craters had."

Conditions Essential for a Volcano. In the light of the preceding facts, we may give several essential conditions which seem to be primarily responsible for the production of many, perhaps all, of the true volcanoes of the world:

1. A large quantity of carboniferous material, such as coal or oil. Some of the best-known examples of such masses of carboniferous material are those in Pennsylvania, South Wales, Vancouver, B. C., or the Latrobe Valley, Australia, the latter place having coal seams with an aggregate thickness of 780 feet, and one single bed over 260 feet thick.

2. These deposits must be buried very deeply in the ground, from 1,000 feet to 10,000 feet or more.

3. Limestone, gypsum, iron ores, or other oxygen-bearing rocks must be associated with the carboniferous beds, and be present in very considerable quantities.

4. A large influx of water upon the fiery mass of molten rock is essential to the production of at least an explosive volcano. Steam is one of the chief substances ejected in eruptions. When water is converted into steam, it tends to expand to about 1,700 times its former volume, which is over five times the expansive force of gunpowder and nearly twice that of guncotton. But even this tremendous expansive force is increased with a further rise of temperature above the boiling point; so that at 962° F. the pressure is about 1,000 atmospheres, or sufficient to lift a weight of nearly *eleven miles* of overlying rock. Thus a few hundred tons of water, in contact with a molten mass of rock, would cause sufficient pressure to shake the earth over vast areas and blow out almost any quantity of rock or melted ore from the chimney of this underground furnace.

Classification. As for a classification of the various forms of igneous eruptions, some authorities make no distinction between the older (really so) and the more modern eruptions.

Others — and the weight of evidence is on their side — make a fairly clear distinction between the massive sheets of igneous rocks which seem to have flowed out quietly from fissures or multiple vents, and those produced in modern times by true volcanoes, effusive or explosive. The former appear to have taken place often beneath the waters, or at least upon wet sedimentary beds, and were probably caused by the intense heat attendant upon the prodigious shattering and dislocation of the Archæan rocks which are in evidence over almost every part of the globe, the mechanical movements which generated this heat being in some way connected with the causes producing the movements of the oceans which in turn produced the stratified deposits themselves.

True volcanoes, on the other hand, seem to be more modern in origin. In many instances, their heat may have been partly started by the other sources of heat just mentioned, and also by the intense heat developed by the mountain making after the laying down of the sedimentary strata, this mountain making having been by no means a slow, gradual process. But true volcanoes are confined exclusively to the stratified or sedimentary rocks, and seem to be dependent for their heat mainly upon the subterranean oxidation of carboniferous matter and the chemical changes accompanying this oxidation; their explosive action being due to the expansive forces of the vapors thus generated, largely to the expansive forces of superheated steam. They have no more to do with the fabled molten interior of the earth than have the smokestacks of locomotives.

FIG. 141. Lower end of Reelfoot Lake, Tennessee, showing in the distance several trunks of trees killed by the submergence of this area, which occurred at the New Madrid earthquake, 1811. (Fuller, U. S. G. S.)

CHAPTER XIII

Earthquakes and Diastrophism

General Remarks. The modern scientific knowledge of earthquakes may be considered as having been initiated by Robert Mallet, who issued a notable work on the Neapolitan earthquake of 1857. The Charleston (1886), Assam (1897), San Francisco (1906), and Messina (1908) earthquakes have added to our knowledge, until "there is perhaps no field of geological inquiry in which greater progress has been made, especially in recent years." (Pirsson.)

An earthquake may be defined as an undulatory or trembling motion in the rocks of the "solid" earth, this motion having been communicated to the visible part of the earth by some shock. The question is, *What causes the shock?*

Violent volcanic outbursts, such as those at Krakatoa and other centers, which we have already spoken of, have been accompanied by light earthquakes of quite limited extent. The

sudden falling in of the roof of a subterranean cavity has in some instances produced distinct shakings of the surface. In December, 1811, and January, 1812, a series of earthquakes accompanied an extensive depression of the surface some 75 miles long and 30 miles wide, near New Madrid, Missouri. Perhaps on account of the lack of accurate scientific observation at the time, it is now difficult to determine whether the earthquakes were the cause of the subsidence of the surface, or whether this subsidence was itself the chief cause of the trembling of the ground. At any rate, the large region spoken of above seems to have dropped bodily several feet, enormous fissures appeared in the ground, and great lakes were formed, one of which, Reelfoot Lake (Fig. 141), east of the Mississippi,

FIG. 142. Plicated beds on unfolded ones. Mineral Ridge, Nevada. (U. S. G. S.) (After W. B. Scott, "Introduction to Geology," permission of Macmillan Co.)

is 20 miles long and 7 miles wide, "and so deep that boats sail over the submerged tops of tall trees." ("Encyclopædia Britannica," Vol. 18, p. 613.) In another part of the area affected, a ridge "twenty miles in diameter was bulged up athwart the channel of the Mississippi." (Norton.)

The San Francisco Earthquake. Such things give us some idea of causes which may occasionally contribute to earthquake action; but neither of the two causes just mentioned is the leading cause of earthquake phenomena. "It has now been rather

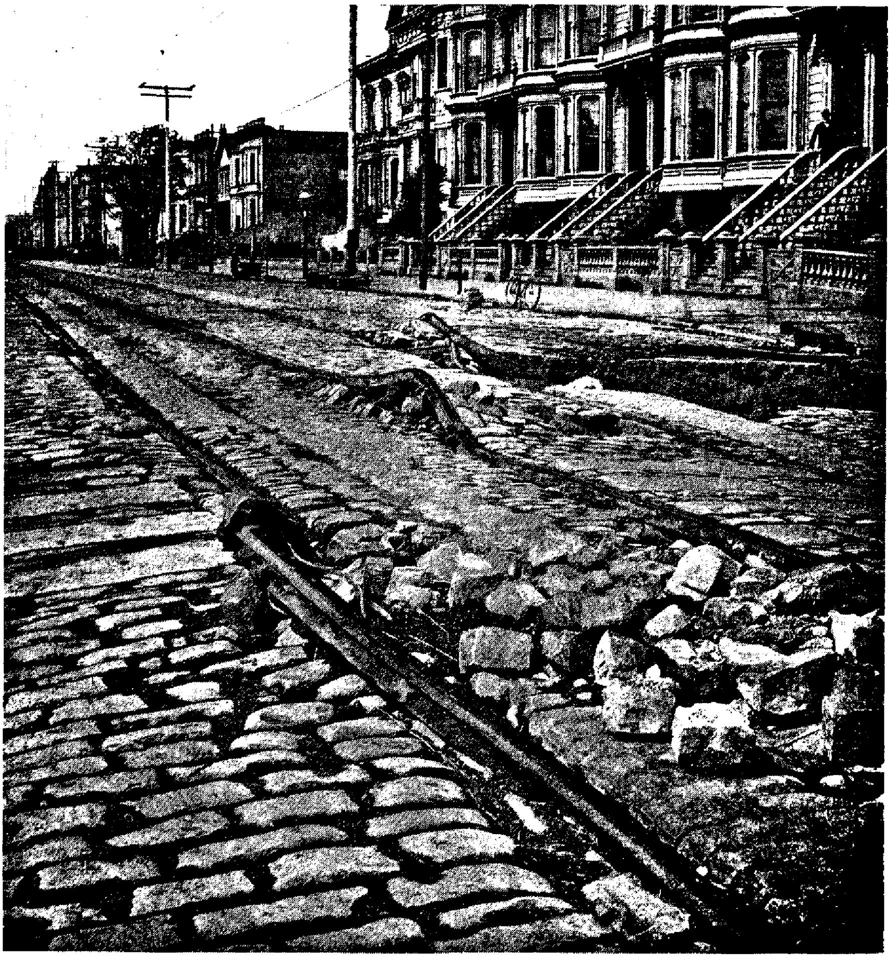

FIG. 143. Buckling in the railway track, Howard Street, San Francisco, California, caused by the ground on the right of the foreground settling and moving forward. San Francisco earthquake, 1906. (Gilbert, U. S. G. S.)

definitely settled that the main cause of earthquakes, especially the heavier ones, is the jar given the earth's shell by the sudden forming of a fracture in its outer portion, or, perhaps, *a sudden slipping, or displacement,* along the walls of an already existent fracture." (Pirsson.) It is thought that the outer part of the earth's surface is cut up into blocks, large and small, and that such fractures or division lines die out below at a depth of some 12 miles or less. Within this *zone of fracture* or displacement, great *faults* are known to extend across various parts of the lands, some of them being many hundreds of miles long.

For instance, the great break concerned in the *San Francisco earthquake* of April 18, 1906, has been followed, with a few interruptions, for about 600 miles, and is called the *San Andreas Rift* (Fig. 144). At many times previously, it seems, displacements along this line had already taken place, the one connected with the San Francisco earthquake being of the nature of a horizontal displacement of the two earth blocks on the opposite sides of this fault or rift, the eastern side moving southward, and the western side moving twice as far northward, the maximum horizontal displacement being 21 feet, with an average of about 10 feet. Fences and roads running across this fault were afterwards found to be just so much out of line (Fig. 145). The movement of the earth, and thus also the violence of the shock, diminished in proportion to the distance east or west from this fault line. Toward the north, there was a slight vertical displacement of from one to three feet.

From the study of this and other earthquakes, it seems evident that the real shock is caused by the *sudden giving way of the rock* which has been under a tensional strain, this strain perhaps having been gradually accumulating for a long time. Milne has pointed out the probable connection between earthquake frequency and the *wandering* of the pole of the earth from its mean position (Fig. 146). According to this author, earthquakes have been most noticeable at times when the displacement of the pole has been larger than usual, or when there has been a sharp change in the direction of this movement. This would point to an astronomical cause as the ultimate one; and it would lead us to ask whether what we are now experiencing may not be but the gradual adjustment of the earth to similar causes of far greater intensity which may have operated in the past. In the present state of our knowledge relative to the matter, it may be impossible to

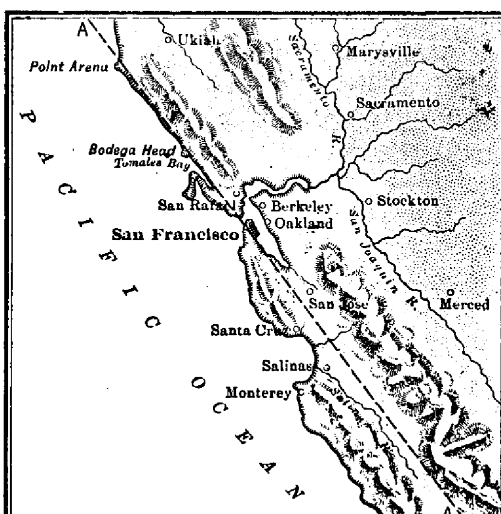

FIG. 144. Map showing the position and extent of the fault-line, A—A, movement along which produced the earthquake of April 18, 1906.

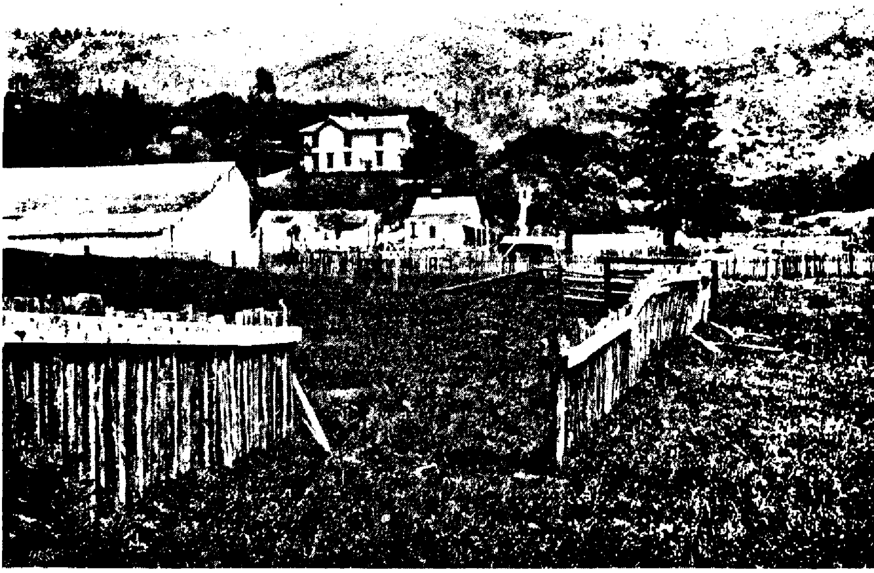

FIG. 145. Fence offset 8½ feet, by the main fault of the San Francisco earthquake, one half mile northeast of Woodville, California. (Gilbert, U. S. G. S.)

settle this point definitely; but there are many facts which point in this direction.

It is important to remember that the displacements accompanying earthquakes are not caused by the shaking of the ground, *but the shaking of the ground is caused by the displacement in the earth.* In many instances, the amount of this displacement has been much greater than was noted in the case of the San Francisco earthquake. In the Mino-Owari earthquake, in October, 1891, in Japan, a fault was traced for a distance of nearly 50 miles which in some places showed a scarp with a vertical *throw* of 20 feet, while the amount of displacement underground is supposed to have been in places much greater. But in the rocks in all parts of the world, ancient displacements have been detected which often have throws of vertical range measuring from ten to a hundred times this amount. And if these also were *suddenly* brought about, as all analogy seems to indicate, there must at some time in the past have been earthquakes of indescribable violence.

Other Examples. The *Messina earthquake* of 1908 had its center near the Strait of Messina, between Italy and Sicily, practically wiping out the towns of Messina and Reggio, with a loss of life of possibly 200,000. This being so near the ocean, it was accompanied by marked tidal phenomena, giving us some idea of what an earthquake is capable of in the way of a disturbance of the waters. "At first the sea retired, and then a great wave rolled in, followed by others generally of decreasing amplitude, though at Catania the second was said to have been greater than the first. At Messina the height of the great wave was 2.7 meters, whilst at Ali and Giardini it reached 8.4 meters, and at San Alessio as much as 11.7 meters." (Rudler.) At Malta, nearly 200 miles distant, the wave was nearly 3 feet high. Such waves are not at all like ordinary wind-caused waves, but are *translation waves,* and sweep across the ocean at a rate varying as the square root of the depth of the water, the rate being 38.7 miles an hour in water 100 feet deep, and 122.3 miles an hour in water 1,000 feet deep. "An earthquake at Concepcion, Chile, set in motion a wave that traversed the ocean to the Society and Navigator [Samoan] Islands, 3,000 and 4,000 miles distant, and to the Hawaiian Islands, 6,000 miles; and on Hawaii it swept up the coast, temporarily delug-

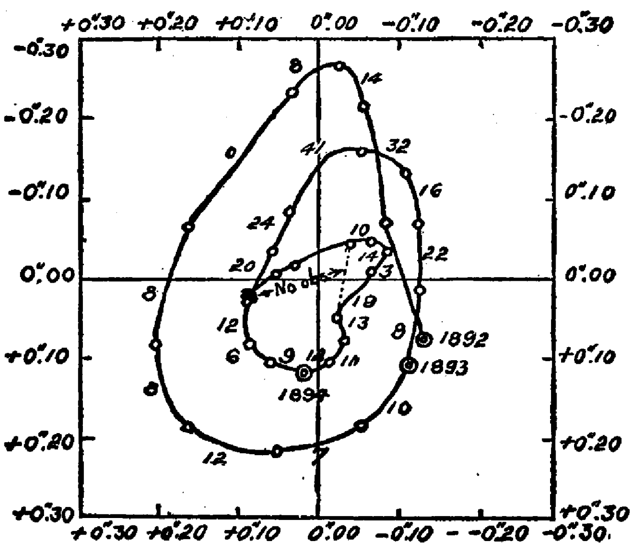

FIG. 146. Diagram to illustrate the "wandering of the pole," or what is more commonly called the "variation in terrestrial latitude." (After Milne.) Milne held that when this variation of latitude was greatest, earthquakes were more frequent, thus connecting this wandering of the pole with earthquake phenomena.

ing the village of Hilo." (Dana.) Another earthquake on the coast of Peru, in 1868, sent out waves which were felt in New Zealand and Australia, in the Hawaiian Islands, and on the coast of Oregon, in the United States.

Ancient Earthquakes. Hence, if the displacements so plentifully recorded in the older rocks were similarly *sudden,* and of a magnitude proportionate to the hundreds or even thousands of feet of these displacements, we can well agree with a venerable geologist of the old school that the "sea-borders, continental seas, and land-borders the world over might be *mostly stripped of life by earthquake waves.*" For such "deluging waves sent careering over the land from any seas in the range of the vibrations . . . would have been *destructive over all the coasts of a hemisphere.*" (Dana, "Manual," pp. 375, 878.)

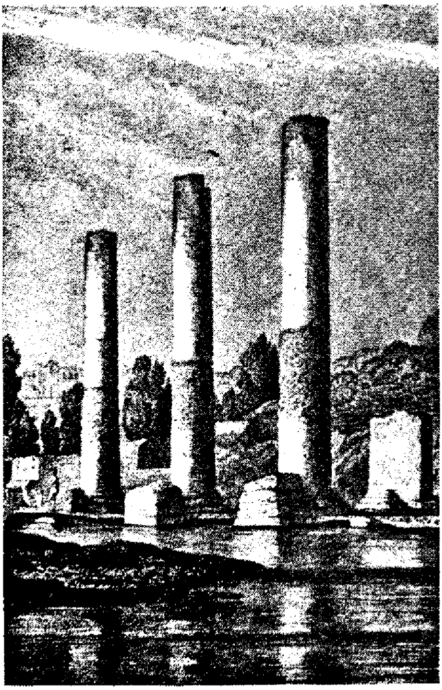

FIG. 147. Ruins of the temple of Jupiter Serapis, on the Bay of Naples, Italy, as they appeared in 1840. (After Lyell.)

That many at least of the great breaks recorded in the rocks were accompanied by tremendous convulsions of the earth, is attested by many of our foremost geologists. The following from Suess is representative of many statements which might be given from others also:

"The earthquakes of the present day are certainly but faint reminiscences of those telluric movements to which the structure of almost every mountain range bears witness. Numerous examples of great mountain chains suggest by their structure the possibility, and in certain cases even the *probability,* of the occasional intervention in the course of great geologic processes of episodal disturbances, of such *indescribable and overpowering violence,* that the imagination refuses to follow the understanding and to complete the picture of which *the outlines are furnished by observations of fact.* Such catastrophes have not occurred since the existence of man, at least *not since the time of written records."—"Face of the Earth," Vol. 1, pp. 17, 18.*

Earthquakes are recorded and their effects made available for study by delicate instruments called *seismographs,* which work on the principle of a heavy pendulum suspended with a pencil or finger attached, this pendulum, by its inertia, remaining at rest while the earth beneath it is vibrating under a shock. The pencil records the path taken by a stationary object.

Diastrophism

Secular Changes of Level. When we pass from this study of surface changes which have been observed in the modern

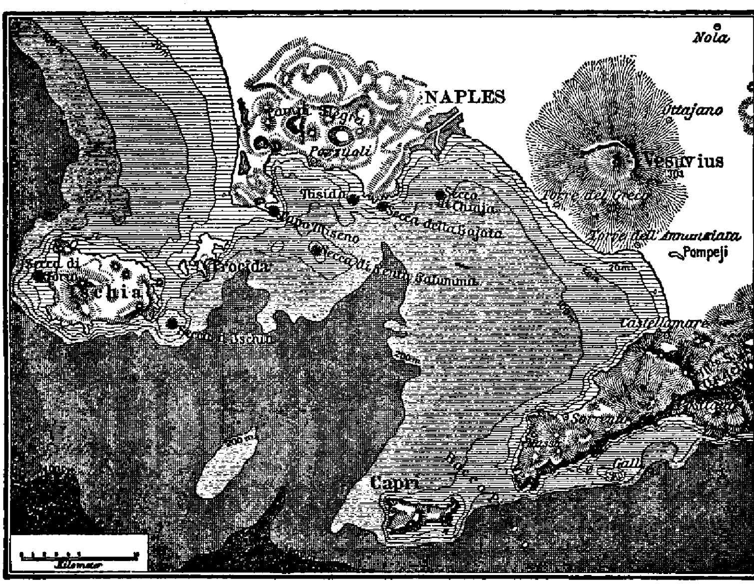

FIG. 148. Map of the region around Vesuvius, showing Pompeji (Pompeii) and Puzzuoli, also several submarine volcanoes. (After Walther, Ratzel, and Grabau.)

world, to interpret the changes which are recorded as having taken place in the long ago, we are met with many difficulties, not the least of which are the theories which have hitherto obstructed the true interpretation of these events. That changes of land and water have taken place in the past, is evident to everyone who has traveled, with his eyes wide open, for a hundred miles in almost any direction. The well-preserved remains of sea creatures are embalmed in the rocks underneath dozens of our cities, and other sea fossils are to be seen high up on almost every mountain range on earth.

"There rolls the deep where grew the tree.
O earth, what changes hast thou seen!
There where the long street roars, hath been
The stillness of the central sea."

But how shall we interpret these great changes? Are there any present-day evidences that the incipient stages of such exchanges of land and water are now going on? For many years, books on geology have taught that such incipient changes of land and water are even now going on, and the records of the

FIG. 149. Ancient sea-caves, formed by wave action, in a former sea-cliff at the back of an elevated beach, showing an elevated strand-line. Coast of Fifeshire, Scotland. (Geological Survey of Scotland.)

past have continuously been interpreted in the light of this supposed fact. In this chapter, it will be well to content ourselves with examining the evidence supposed to point in this direction, allowing the real interpretation of the records of the past to stand over until a later chapter, when we hope to have more data with which to judge concerning this problem, which is really the crucial problem of the whole science of geology. We are in reality only at the threshold of this problem as yet; for we have not yet examined any of these ancient records. We must here consider the preliminary conditions of this problem.

Difficulties of the Subject. When we seek to consider the relative position of the land and the water, we need *some fixed point of reference.* Naturally we think of the *sea level,* or mean tide level, as a fixed point from which to start. In case of any

FIG. 150. Arch in sandstone, at the "Haystacks," near Fort Defiance, Arizona. Probably this was once a sea-cavern. (Darton, U. S. G. S.)

mere local fluctuating of the land near the sea, this would be the natural datum level from which to measure the change.

But we presently discover that the surface of the ocean does not present a true geometric surface, but a surface considerably *warped* by various conditions. Certainly the mean tidal level is not the same distance from the center of the earth at all points of the ocean. The surface of the ocean in the tropics is about 13.5 miles farther from the earth's center than is the surface of the ocean at the poles. Not only so, but in many parts of the world, as we know, the waters are *pulled up onto the lands* by the gravitational pull of the land masses. In localities like the Bay of Naples, it has also been demonstrated that when Vesuvius has its crater full of lava, the water stands measurably *higher on the shore* than it does when the shell of this volcano is empty. This reservoir of lava may fill up gradually, and thus the waters may gradually rise along the shore; but the mountain empties itself *suddenly*, and thus the waters might go down very suddenly. The measurements so painstakingly performed along the shores of the Baltic and the North Sea have been shown to be worthless as accurate scientific records, for it is now known that these waters fluctuate considerably between wet seasons and dry; and at one end of the Baltic, during a storm in that direction, the winds will pile the waters up many feet above the normal level, and will maintain this difference for many days.

These are some of the difficulties encountered in entering upon our subject. That there are changes plainly recorded along many parts of the coast, is very evident. In numerous localities along the shore, barnacles and corals and other sea animals are found many feet above the present ocean level in these respective localities. The classic example of the temple of Jupiter Serapis, built by the Romans on the shore of the Bay of Naples (Fig. 147), is evidence of this sort. Three marble columns of this temple are still standing, their bases at present in the water. For the first 11 feet above their bases, they are intact; but from this point to 19 feet up, they are pitted full of holes bored by the rock-boring shelled animals, *Lithodomi*, the remains of these animals being still in the holes. Evidently these columns must have been beneath the waters for some time, and quite as manifestly the lower parts of the columns must have been *quickly protected* from the action of these creatures by mud or volcanic ashes. It has been argued that the rise and fall of the land on which this temple rests (or the rise and fall of the water, which would be the same thing) must have been

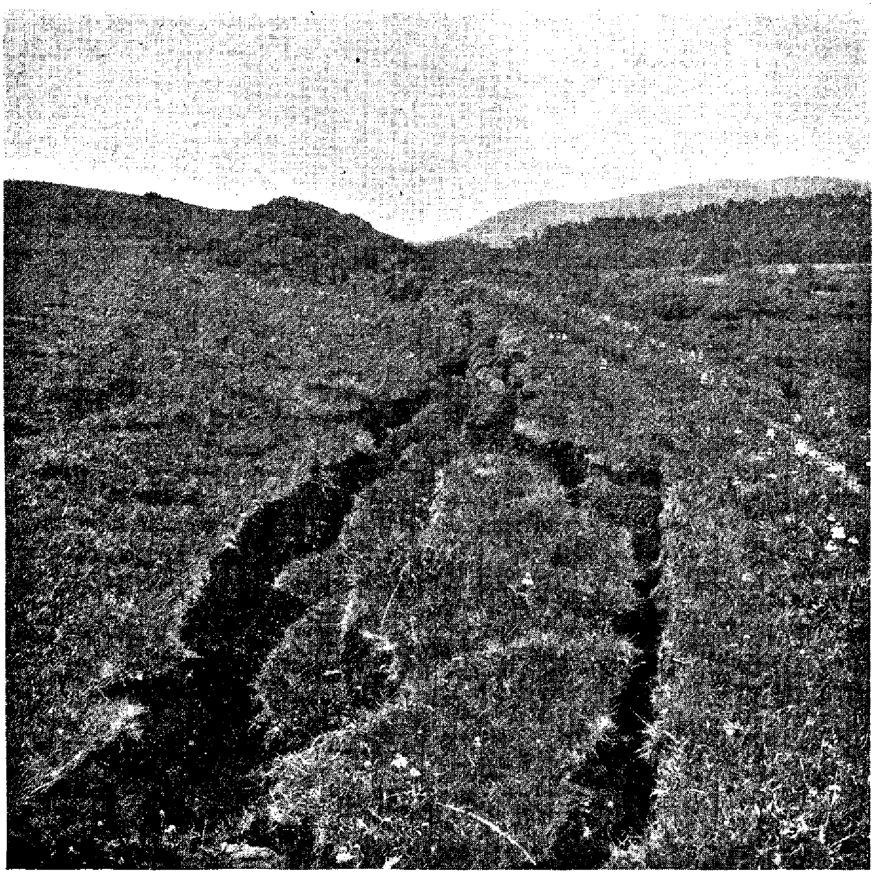

FIG. 151. The main fault between Point Reyes Station and Olema, California, looking southeast. The ground at the right of the fault has moved toward the observer; and that at the left, away from the observer. San Francisco earthquake. (Gilbert, U. S. G. S.)

slow and gradual enough to allow these three columns to remain standing. But it is evident that it *may have been so sudden as to throw down all of the temple but these three remaining columns.* In the absence of authentic records of this place, how are we to interpret the record which we find here engraved for us in these stone columns?

Another evidence of change of relative level is presented by the *raised beaches,* consisting of wave-built and wave-cut terraces, often showing caves formed by the waves (Fig. 149), which are found in many places around the shores of the continents. These ancient marks of the strand-line are eloquent testimony to the fact that changes of either the land or the ocean

have taken place. But again it is well to ask, Do these phenomena indicate a slow, gradual change in the localities referred to, or is it a *sudden change* which they testify to? Surely if it had been a slow and gradual change, the gradation from the old beach to the modern one would have been a gradual one, and all the area intervening between the upper beach and the

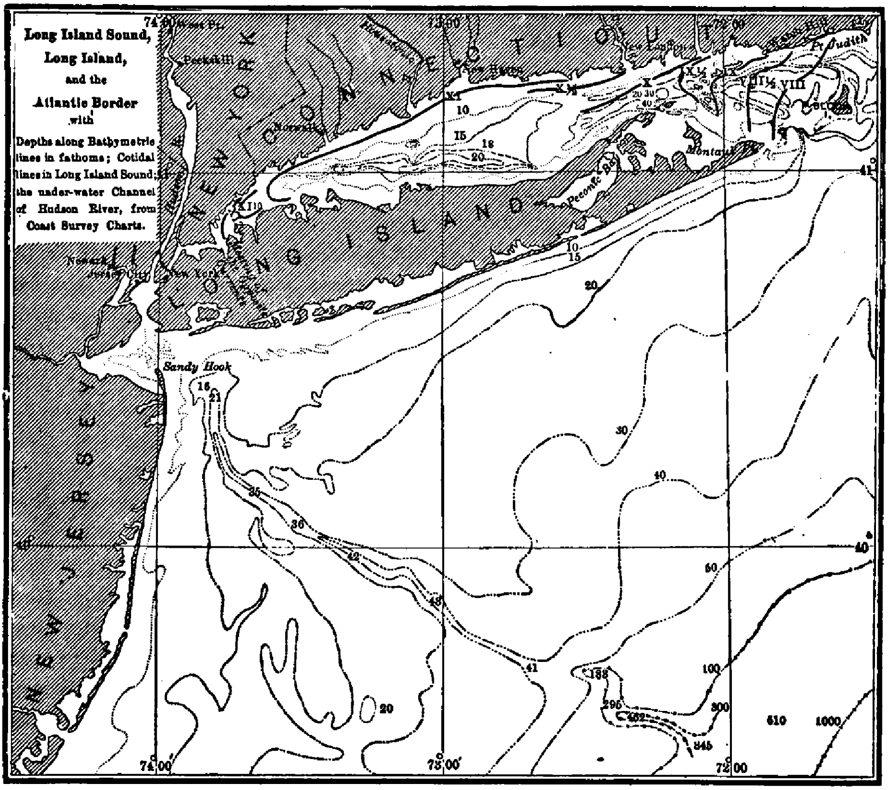

FIG. 152. Map showing the submerged channel opposite the mouth of the Hudson River. The figures indicate depths in fathoms. (After Dana.)

lower (present) one would have *successively gone through the stage of forming a beach for a considerable time,* and hence there would not be the sharp contrast between these two definite marks and the intervening area which has no such marine handwriting upon it. Surely it is some sudden change which we see indicated here, not a gradual one.

The same thing may be said of the *submerged forests* and submerged *peat bogs* found along many coasts, as well as the submerged *wave terraces* found on some of the coral islands. These point to *quick, sudden changes* of level, not to any slow,

gradual change. The warped position of the old shore lines around the Great Lakes tells the same story. These old shore lines are not now all on the same level, as would be the case if the waters had merely gone down in the usual manner through the drying away of the water of the lake, or through the outlet of the lake having been lowered, thus partly draining it; but the shore line at one end or on one side is at a decidedly *different level* from that at the opposite portion. But here again, it seems to me, the facts can be very easily understood as due to sudden changes of level, such as we know often accompany earthquakes.

As for the so-called *"drowned valleys"* opposite the mouths of such rivers as the Hudson, I think that possibly they also could be understood as having been caused by a sudden submergence of the land. But I question whether these so-called "drowned valleys" are really submerged channels. The prolonged estuaries here spoken of *may be caused by the scouring action of the cold salt water of the ebb tide,* which in the winter is chilled while up in the river channel, and which at the retreat, or ebb, would on this account *keep on the bottom* of the warmer surface water of the ocean, and thus form a real submarine river flowing out across the continental shelf, thus scouring out a distinct channel for itself.

The upper Rhone flowing into Lake Geneva, and the upper Rhine flowing into Lake Constance, have both excavated distinct stream channels in the beds of these lakes. Both of these rivers are fed by glacial streams, and their waters are very cold; and when this icy water, carrying great loads of sediment, is emptied into the warmer and lighter water of the lake, it naturally keeps to the bottom. Thus these rivers maintain their courses for considerable distances from the shore and cut trenches across the bottoms of these lakes. And it is self-evident that the cold ebb tides running out of such rivers as the Hudson in the wintertime, might easily account for the so-called "drowned valleys" found opposite their estuaries.

Past Changes Sudden, Not Gradual. Thus in all the various ways in which we can examine this problem of the present-day changes of level along the coasts, we are met with evidence of distinct change, it is true, but the changes indicated seem to be best understood as having been *sudden, and not gradual.* We do know that earthquakes are attended in many instances by sudden and extensive changes in the lands thus affected, some of these changes being in the nature of vertical displacements. And the marks along the coasts may have been due to changes of this character. Certainly there is no positive and unambiguous evidence of slow, gradual changes now in progress.

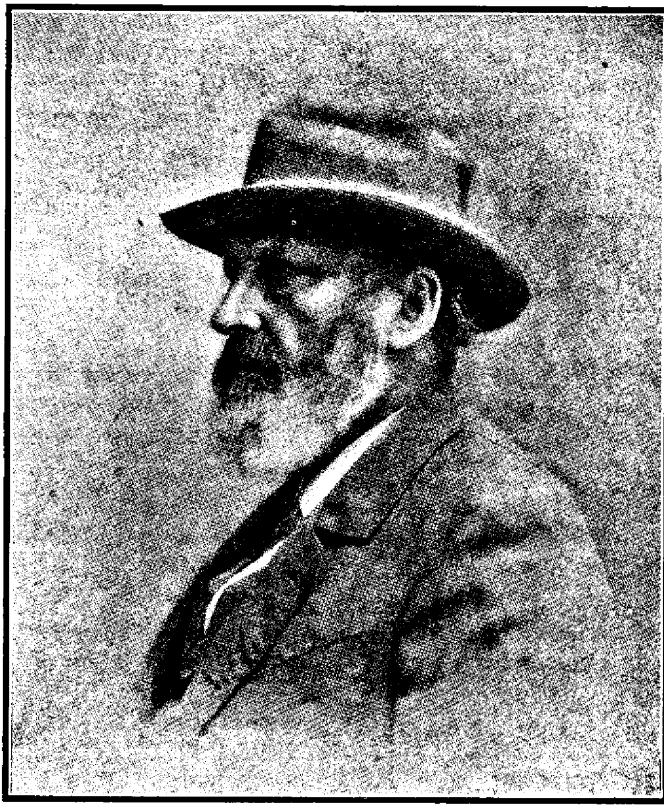

FIG. 153. Eduard Suess (1831-1914), celebrated Austrian geologist; author of *Das Antlitz der Erde* ("The Face of the Earth," Oxford University Press, 1904-1908). Professor Suess during his life was one of the very foremost of modern geologists.

Suess on Secular Changes. And all this is in accord with that monumental work, "The Face of the Earth" (Oxford, 4 volumes, 1904-1908), by Eduard Suess (Fig. 153). The essence of this great work is that we do not find now in progress around our coasts any indications of such exchanges of land and water as we find recorded in all the ancient geological formations. Professor Suess' exact words along this line may be appropriate in this connection. He testifies to the present signs of permanence along the coast:

"Phenomena confront us which testify to the stability of the existing state, which has endured since the remotest period of human tradition, or since a period even earlier still: in hundreds of localities, the sea has graven its mark deep in the rocks at the level of the tide."— *Vol. 2, p. 554.*

After an exhaustive examination of all the recorded observations in Northern Europe and arctic America, he declares:

"Even in these seas, displacements susceptible of measurement have not occurred within the historic period."—*Id., p. 497.*

In reviewing all the available evidence, he makes the following statement:

"We find ourselves confronted with so many circumstances which may exert an influence on sea level, by so much uncertainty in the existing data, and by so many sources of error, that finally little remains of many years' labor, but a conviction that many doctrines which in spite of unprejudiced authorities have become accepted dogmas, are erroneous."—*Id., p. 24.*

And also the following:

"Thus, as our knowledge becomes more exact, the less are we able to entertain those theories which are generally offered in explanation of the repeated inundation and emergence of the continents."—*Id., p. 295.*

It is only just to point out that Professor Suess has a theory of his own, which is that the bottom of the main part of the ocean itself has probably been oscillating up and down, thus affecting the lands of all the continents simultaneously. His reasons for this are not objective, physical reasons, but are based on the prevailing theories of the successive kinds of life alleged to have lived in the successive geological "ages"; for he argues that only by a *universally acting cause,* like the rise and fall of the ocean all over the world, would it be possible "to employ the same terminology to distinguish the sedimentary formations in all parts of the world." This matter will be considered in the proper place, and must not detain us here. But it should be remembered that, even if this substitute theory of Suess' should prove inadequate and based wholly upon wrong assumptions, the completeness of his *destructive criticism of the current theories* about the rise and fall of our modern coasts

FIG. 154. Earthquake crack filled with sand, Charleston, Missouri; formed at the time of the New Madrid earthquake, 1811. (Fuller, U. S. G. S.)

is not thereby affected in the least. This destructive criticism is complete and final; and it should now be regarded as settled that *no modern changes of the sea and land have been proved which will help us in solving the problem of how the ancient changes took place.*

The subject of *mountain making* will be considered in the next chapter. In connection with this subject, we shall see that mountain making in general may be understood as chiefly due to the elevation of the whole region involved and the subsequent erosion of the strata in places, leaving mountains of denudation or erosion. At any rate, whatever we may consider as the cause of mountain making, the formation of the mountains is generally regarded as belonging to *quite another series of phenomena* than the causes which produced the exchange of land and water areas, or the great aqueous transgressions recorded in the stratified rocks.

CHAPTER XIV

Mountains and Mountain Making

Definitions. Mountains may be defined as masses of strata or of ancient crystalline rocks elevated considerably above the general level of the country. Thus we can not draw any definite line between mountains and hills; for even the highest peaks of the Appalachians or of the Ozarks would seem like hills if placed alongside the giants of the Andes or the Himalayas. On the contrary, the enormous pinnacles surrounding the Grand Cañon of the Colorado would, if removed and set down bodily on the Atlantic coast, become the most notable elevations of land east of the Mississippi; yet, where they are, they present merely slight contrasts with the surrounding country, aside from the gorge itself. It seems to be the general impression that mountains are chiefly the results of a wrinkling or puckering of the rocks composing the crust of the earth. But it would be just as accurate to represent them as *the results of erosion acting upon portions of the crust which have been slightly elevated above the common level.* Certain it is, however, that the making of the mountains *belongs to the past,* instead of to the present, except in so far as erosion may even now be carving out the bases of them, thus rendering their outlines more distinct.

A series of peaks more or less in line is spoken of as a *range;* though several distinct series may be included in this term. A series of ranges, more or less independent of each other in appearance, but composed of the same kinds of rocks (geologically), or else having the same kinds of strata on their flanks, are spoken of as a *mountain system,* and are regarded as a geological unit. A combination of mountain systems, such as we see in the Andes, or in the general collection of mountains on the west of North America running from Panama to Alaska, being nearly a thousand miles wide in the latitude of Colorado or Wyoming, is called a *cordillera.*

Classification. Mountains are usually classified according to their origin as *igneous* mountains, mountains of *erosion,* and mountains formed by *movements* of the crust of the earth. As we shall see later, this is not an altogether satisfactory method of classification; but it will serve our purpose for the present.

Mountains of igneous origin may be again subdivided into two classes, of which the first are the true *volcanoes,* such as Vesuvius, Shasta, Cotopaxi, and the mountains of Hawaii, with

Fig. 155. View of the Sierra Nevada range, Inyo County, California, from the eastern side of Owens Valley. Note the horizontality of the sky line. (Walcott, U. S. G. S.)

many others of the highest peaks in the world. The Hawaiian volcanoes can be regarded as 30,000 feet high, if we reckon them from the bottom of the neighboring ocean, from which they arise. The giant peaks of the Andes would lose about half their height, if reckoned in the same manner; for they arise from elevated regions or plateaus which are from 12,000 to 14,000 feet high already, only about 10,000 or 12,000 feet of actual mountain height appearing above these plateaus.

The second subdivision of the mountains of igneous origin are spoken of as mountains of *intrusion,* being regarded as

FIG. 156. Looking across the upturned edges of tilted strata, near Blue Creek Cañon, Oklahoma. This suggests that comparatively level country, or even the prairies, may have tilted strata underneath the surface. (Gould, U. S. G. S.)

having been formed by the intrusion of igneous materials between or among masses of stratified rocks, the whole having since been subjected to considerable erosion, leaving the hard igneous interiors exposed, since these parts are more resistant to the wearing effects of erosion and denudation. The Henry Mountains of Utah and the West Elk Mountains of Colorado are regarded as having been made in this way. But where the core of a mountain range consists of granite or of other crystalline rocks, often it is impossible to say whether these mountains may not more properly be considered as *primitive.* And this is the case with some of the most massive mountain ranges in the world. Pikes Peak, Colorado, may be regarded as of this

class, with numerous ranges among the Rockies, the Alps, the Caucasus, and many others.

But very many of our more familiar mountains are merely the *peaks left by the dissection and erosion of an uplifted area of country.* All the Catskill Mountains of New York are of this class, also many of the buttes in the plains region of the West, most of the mountains in the Glacier National Park, with such conspicuous peaks as Chief Mountain and Mount Cleveland, and also Crowsnest Mountain, and Mount Rundle and Cascade Mountain, near Banff, in Alberta. Indeed, all these front ranges of the Rockies from the middle of Montana up to Mount Robson and beyond, in Alberta, ought properly to be considered as merely mountains of erosion. True, they show evidences of slight disturbance here and there; for no large area of this size is ever quite free from minor disturbances. But they have all the appearance of being merely the dissected remnants of a great mass of nearly horizontal strata once elevated into a high plateau. Doubtless many other mountain ranges in the Alps and elsewhere, which have been called "folded" or "faulted" mountains, and for the explanation of which many wonderful theories have been invented, should be regarded as only examples of erosion acting on nearly horizontal beds, which, because they do not happen to occur in the accepted order of sequence looked for by geologists, are supposed not to be now in the positions in which they were first deposited, and hence some complex folding or faulting of the strata is alleged to have occurred since their deposition.

Mountains Caused by Earth Movements. Mountains caused by movements of the earth's crust are usually subdivided into three classes: *block* mountains, *folded* mountains, and mountains of *complex structure.* We shall describe them under these heads, and frame our conclusions in reference to them after having examined their characteristics.

The term *block mountains* is given to those peaks of nearly horizontal strata which have high fault-scarps more or less dissected on one side, with long, gentle slopes on the other, the beds all dipping in the direction of the gentler slope. Sometimes it appears that two or more parallel sets of these block mountains run across the country, the slopes of these various ranges being all more or less in the same general direction. The north and south small ranges in the Great Basin, between the Wasatch Mountains and the Sierra Nevada, are regarded as of this type, as are also the mountains of Southern Oregon and Northern California and Nevada. But no sharp line of dis-

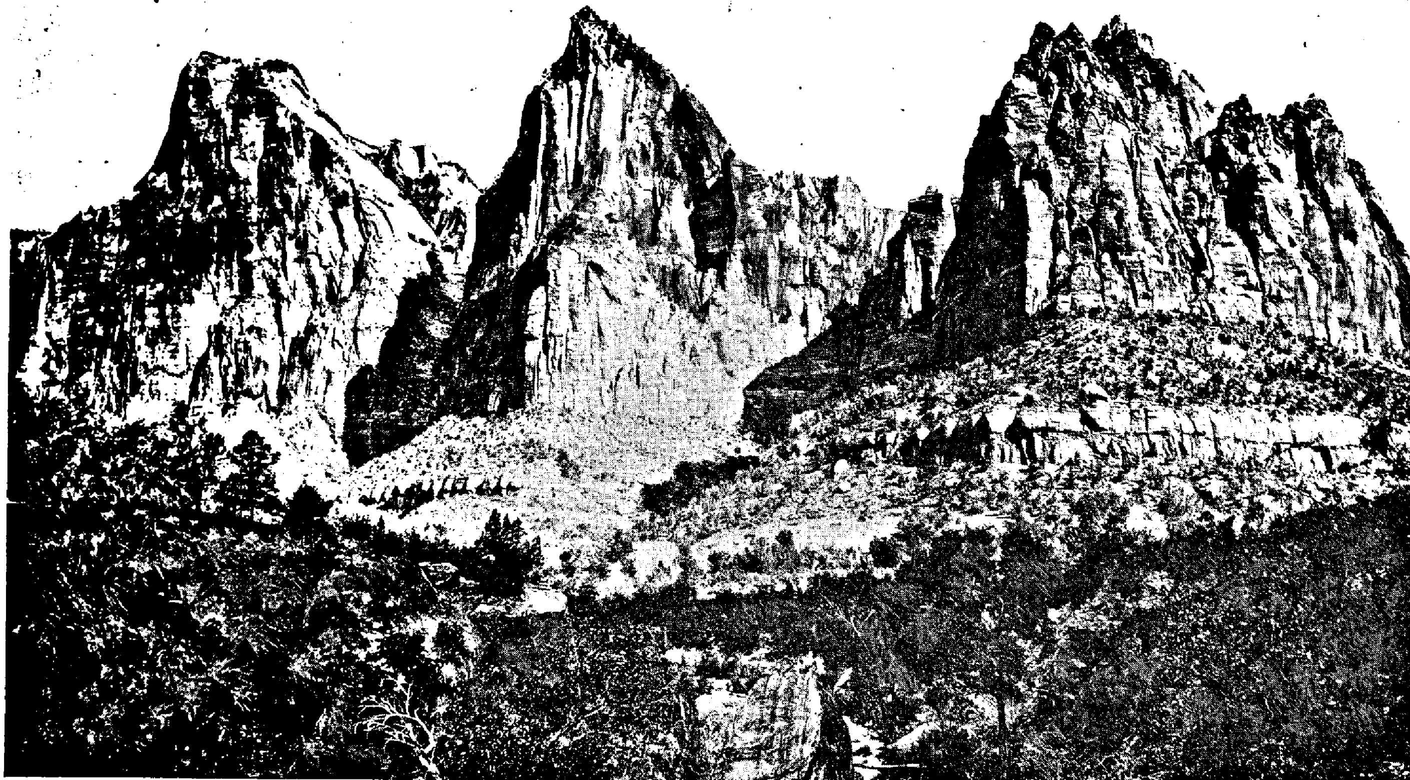

FIG. 157. The Three Patriarchs, Mukuntuweap National Monument, Utah. Each stratum in one of these buttes is found at the same level in the others. Evidently the land was once level above the tops of them all. The materials eroded from these regions, as well as from the Grand Cañon of the Colorado, have been carried down and now help to compose the delta of the Colorado and the floor of the Imperial Valley. (U. S. G. S.)

tinction can be made between these so-called block mountains and what are called *folded* mountains, nor yet between either of these classes and ordinary *mountains of erosion,* such as we have already described. Too much theory as to the relative ages of the strata composing these mountains enters into the distinctions made between them.

The Jura Mountains, between France and Switzerland, are usually pointed out as typical examples of mountains composed of a series of wavelike *folds.* They consist of a number of parallel ranges trending northeast and southwest, each range appearing to be bowed up like an arch, and the valleys being like the troughs of these wavelike folds. Much of the material once composing the peaks of the arches has been eroded away and now partly fills the intervening troughs. But the whole range is composed of strata once laid down horizontally in the sea, for an abundance of sea fossils are contained within them, though now they are many thousands of feet above sea level.

But by far the greater number of mountain ranges are so highly complex in their structure that they are usually classed together as *complex mountains.* Such are the Alps, the Hima-

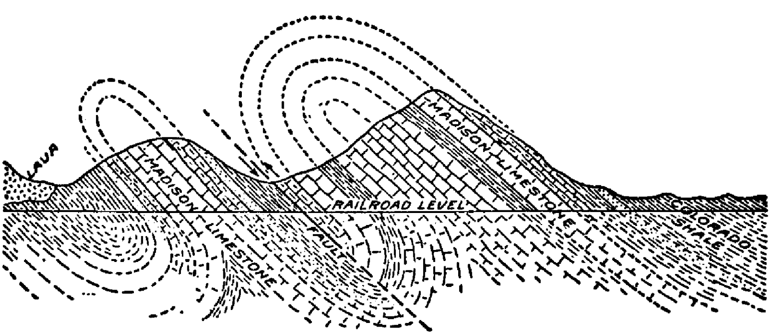

FIG. 158. Section (imaginary) near Livingston, Montana, where Madison (Mississippian) limestone is repeated three times, with strata of different age intervening. These huge folds are imagined to have taken place here, in order to explain this serial repetition of the same kind of beds. We must remember that all the drawing below the horizontal line is absolutely imaginary, as are also the folds pictured above. (U. S. G. S.)

layas, and many of the individual ranges of the Rockies. As already remarked, there is no sharp line of distinction to be drawn between the mountains of this type and mountains like the Juras, which are obviously made up of wavelike folds. And these complex mountains present so many diverse types of structure that it is difficult to do more than point out a few characteristics common to very many of them. Their majestic peaks constitute the most elevated portions of the earth, and

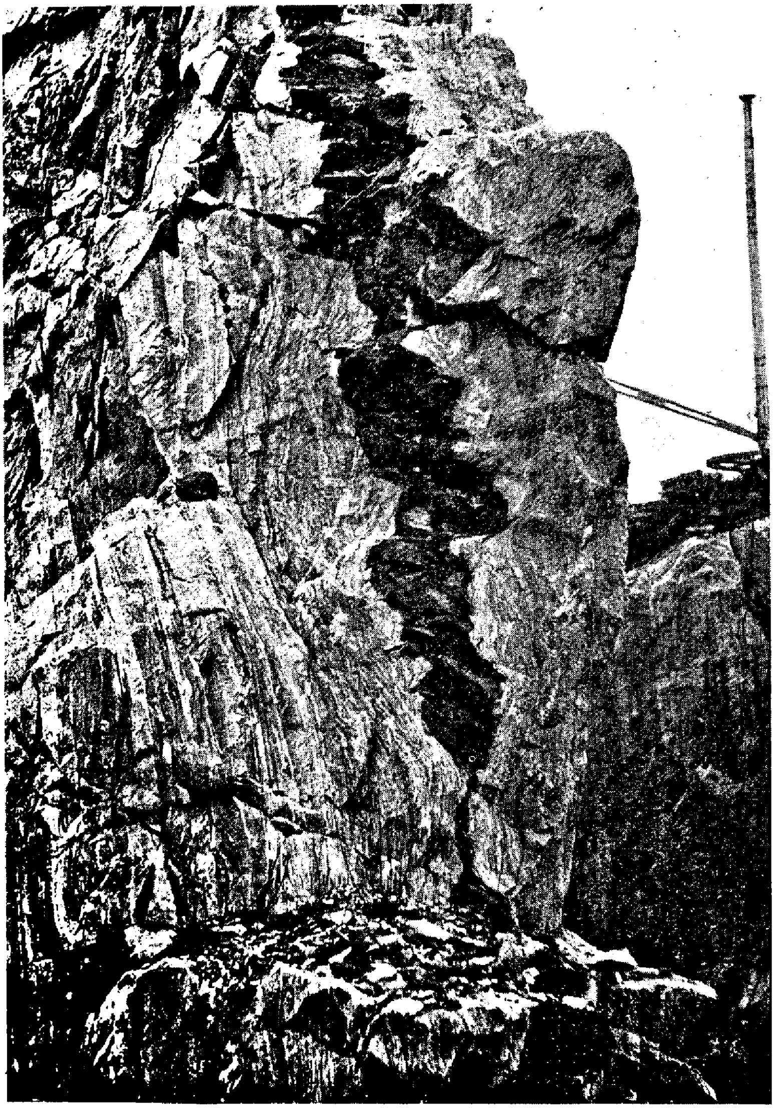

FIG. 159. Fractured basic dike in crystalline limestone, 15 feet wide in places. The limestone has "flowed," while the dike has been "fractured" by the subsequent changes. Near Rockland, Maine. (Bastin, U. S. G. S.)

these peaks are merely the most resistant portions of much larger masses which once existed, these peaks being left standing while all the rest has vanished. These lofty ranges are generally so much changed in structure by processes of metamorphism that it is impossible to say what was their original

structure; though there is great probability that many of them represent *primitive or original mountain structures* which have remained during all the vicissitudes through which the earth has passed.

Assigning Dates. The method employed in assigning a *geological date* for the uplifting of a mountain range is simple enough, but it is based entirely on the prevailing theories concerning the dates to be assigned to the various kinds of fossils. As will appear in a later chapter, the stratified rocks are all classified according to the fossils which they happen to contain, these different groups of fossils being regarded as strictly chronological, so that the relative dates of the strata can be assigned to them wholly on the basis of the fossils they contain, and wholly irrespective of whether they are made of limestone, sandstone, shale, or any other kind of lithic structure. Of course, this is a *purely theoretical arrangement,* and as we shall see presently, is not only highly artificial, but is utterly false and erroneous. Hence it may be supposed that the dating of the elevation of the mountain chains would be a very uncertain business, and might result in making the structure of a mountain range very unnecessarily complicated; which is indeed the case.

But the method employed is to date the mountain *subsequent* to the "newest" strata composing any part of the range which has participated in the elevation, and *earlier* than the "oldest" strata resting unconformably against the flanks of the range — if any such can be found. As might be imagined, the dating of the mountain ranges of the world has kept a large number of men busy for a couple of generations, and whole libraries of books have been written upon the results of their herculean labors. The general outcome of it all has been that the mountain ranges over most all the globe are *astonishingly "young,"* since they contain strata which can not be assigned to the older ages of geological history; and hence the amazing conclusion is reached that the making of these mountains — that is, the making of almost all the great mountain ranges of the globe — must have taken place more or less contemporaneously, and *at the close or near the close of the long stretch of what is called the geological ages.* This is a most surprising and a most interesting conclusion; but the further consideration of this fact must be left over for another chapter.

Speculations. In following out the theory of the dating of the fossils, and thus the dating of the strata in which they occur, it is no wonder that the perplexed geologists were often put to their wit's end, in an endeavor to account for the strange and unlooked-for positions in which these strata were found in such mountains as the Alps. These mountains were complex enough to begin with; but an arbitrary theory as to the relative order of the strata made matters a thousandfold worse; and so

for over half a century, following the lead of Dr. Albert Heim and other Continental geologists, the textbooks have always provided us with elaborate diagrams which pictured these mountains in cross section, with huge folds many miles high in the air to show where the strata once were. We have also been treated to fairy stories about the strata now composing the Alps having originally been spread out over a width of from 400 to 750 miles, which by lateral pressure has been reduced to about 100 miles, the extra amount, of from 300 to 650 miles, having been absorbed in gigantic folds and thrust faults.

To confirm the theory, the mechanics of the thing had to be illustrated. And so pressure boxes were brought into use, by which layers of clay or cement or wax or what not were subjected to strong lateral pressure, to see how these layers would act under compression; and of course, the structures developing in these pressure boxes had to be looked for in the various mountain ranges, and if not found there, were imagined as possible, and again drawn out as diagrams for wondering schoolboys to study and admire.

Such is a part of the pseudo-science of geology and physical geography with which the civilized world has been afflicted for nearly two generations. And if, under such guidance, we have not made much progress in working out a knowledge of how the mountains were actually formed, the results are not greatly to be wondered at. However, a few stray facts have come to light during the process; and we shall do what we can to make an application of them, trusting to further developments and future discoveries to make the subject still clearer.

Probable Causes of Folding. When rocks of great thickness are cut through by any means, either by erosion or by the act of man, as in tunnels, mines, or open cuts, the *weight* upon the lower strata whose supporting sides have thus been removed often proves too much for these lower layers to stand. The result is, these lower beds begin to *"creep,"* as it is termed in mines, or to flow almost like a semiliquid mass, as was observed in the Panama Canal. The bed of the Chicago drainage canal, composed of limestone, buckled up into a low anticline when the overlying load of rocks had been removed. Innumerable examples of very similar phenomena could be given from the long history of mining and tunneling operations, illustrating the general principle that strata which become overloaded and which are not sufficiently supported on the sides, *will become contorted and will even flow out laterally,* allowing the upper strata to settle down.

FIG. 160. Shales which have broken down by superincumbent weight, or creeping. One half mile north of Columbia, Lancaster County, Pennsylvania. This creeping is evidently of modern occurrence. If this had occurred before the consolidation of the strata, the rocks would have crumpled or folded, and would not have broken, as they have done here. (Walcott, U. S. G. S.)

We have only to apply this principle in a large way, in order to explain practically all the mountain structures of the world, provided we are willing to forget the traditional theories regarding the relative ages of the various strata, and are willing to assume that these strata were mostly laid down during one rather long process, but a process which did not permit much of the first deposits to *consolidate* before the others were piled on top of them. And since uniformitarian geologists have been so free at imagining things, it may be allowable to attempt to picture how these matters would work out, on the supposition of a great world catastrophe, such as seems to be the logical induction from the sum total of the facts about the fossiliferous deposits.

If now we have successive layers of limestone, sandstone, shale, etc., piled up from one to three miles deep, but *all more or less unconsolidated,* because only recently laid down, and if all this mass is elevated into a high plateau, with the forces of erosion beginning to act upon it, we would very soon have the mass cut up into blocks, with wide valleys running in different directions across it. With the supporting sides thus removed, the beds at the bottom of the high cliffs could not well support the load upon them, but would necessarily give way and flow outward, allowing the upper strata near the edge of the eroded section to lop down or settle, presenting the appearance of a part of a syncline. If a similar condition prevailed on the opposite side of the eroded section, we might have a perfect semblance of a syncline from both sides.

As is well known, however, oftener the *crests of anticlines* have been eroded away, many streams and rivers now flowing where once high ridges and anticlines existed. To the present writer, this seems good evidence that such erosion must have been started while yet the *water stood over the entire mass.* Such may not always have been the case; but this is the easiest way to explain the phenomena. *Rivers don't begin to run along the crest of a ridge,* even if this crest is badly broken up by the rupture of the strata; and the long stories of the history of such rivers with which we have been entertained for many years, are not altogether convincing. On the other hand, it is easy to understand how we might now find a river channel running along what was once the ridge of an anticline, if we suppose that the *first* washing away of these broken rocks along the ridge was performed *while the waters of the sea were retreating from the general surface of the emerging land area,* thus

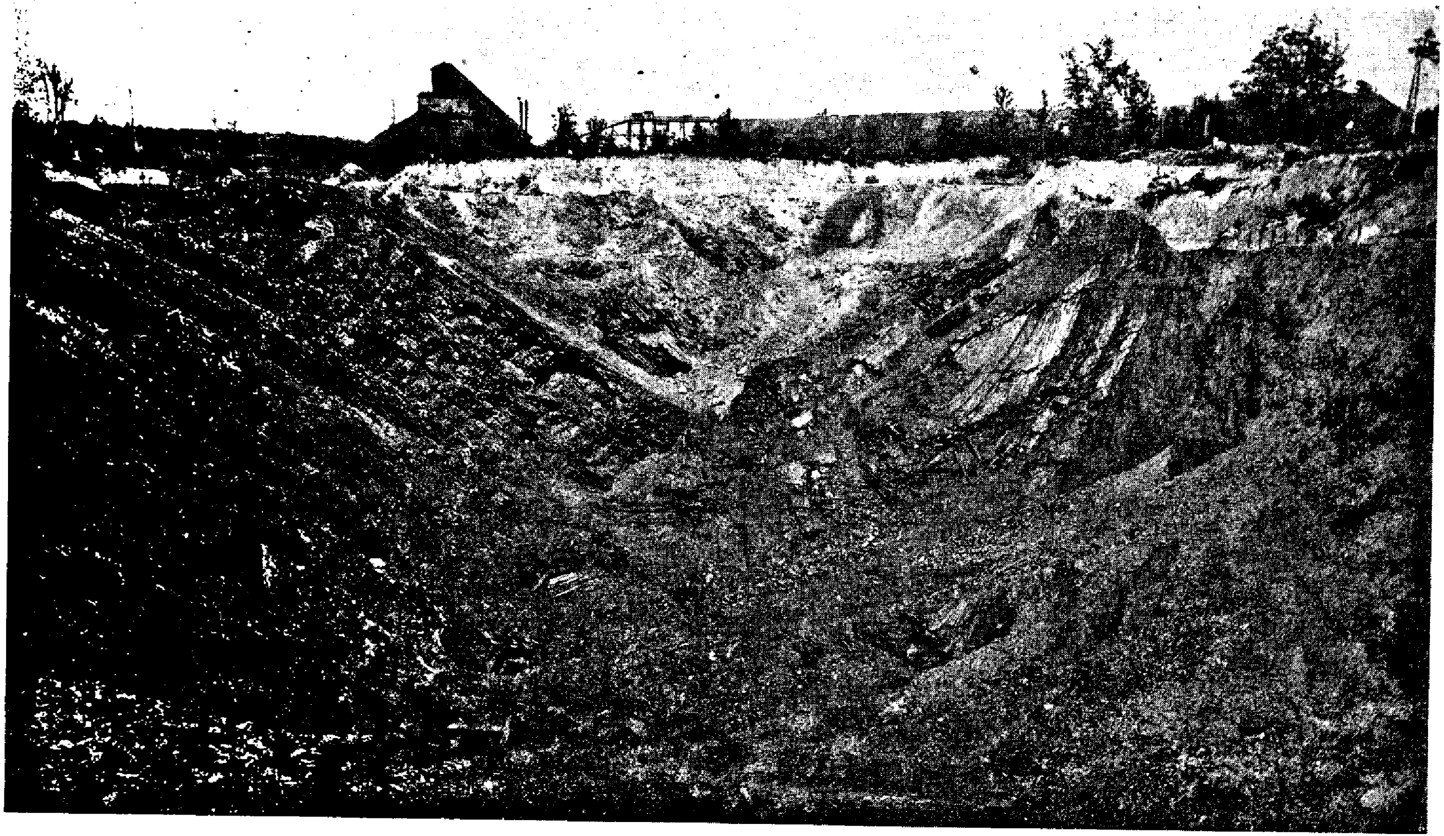

FIG. 161. A cave-in at Hollywood Colliery, Hazleton, Pennsylvania, causing what looks like a small syncline. In the Mammoth Vein. (Hardin, U. S. G. S.)

forming the outline of a channel which would subsequently be occupied by a river.

Probably Unconsolidated Strata. That in every mountain range we have structures which in their appearance would seem to indicate that the strata were still soft and unconsolidated when they were folded and otherwise disturbed, is a well-known fact. The following is from De la Beche, the first director-general of the Geological Survey of Great Britain:

"The question of how such a volume of matter as that composing the contorted calcareous Alps was sufficiently softened, if previously indurated, or kept soft, if never consolidated as rocks usually are, before acted upon by the contorting cause, appears to be one of no ordinary difficulty; and this difficulty not only attends this case, but also an abundance of others. As we might expect, shales and clays are frequently contorted in a disturbed district, while associated limestones and sandstones are merely fractured. *The harder strata have snapped, and the softer have bent.* There is nothing in such phenomena which is not readily understood. When, however, we find *hard siliceous and other sandstones, compact limestones,* and *even brittle substances, twisted and bent into every imaginable shape, and requiring a very soft yet tenacious condition of matter,* the subject is anything but easy."—*"Geological Researches," p. 132.*

In this connection, this author declares that in many instances, the chief evidences of contortion seem to be in the strata on the flanks of the mountain chains, with appearances to indicate that there was at some time a strong "pressure from the central parts *outwards,* causing the lateral contortions we observe." (*Id.,* p. 128.) Such could easily follow if the supporting flanks of a deep mass were partly removed, and the main part should settle down in place, perhaps under earthquake action, thus pushing outward the strata lying against it, as we have described above.

But two other conditions need to be considered as having existed at this same time. First, not all of the underlying strata were equally *competent* to support the loads placed upon them, even without any erosion. For in places, many layers of fresh vegetable matter were laid down, or vegetable deposits, which if not fresh in one sense of the word, were at least not compressed or consolidated; also it would take at least ten times the thickness of pressed plants which we now find in various places composing our coal seams, to produce the materials of these seams. And these beds of plant remains would necessarily settle, and would thus allow the neighboring strata to become more or less disturbed as a consequence.

Lastly, we have the disturbances of which earthquakes are the symptoms, acting upon these masses of piled-up strata

which were as yet only partly settled into place and only partly consolidated. We know, from our study of seismic phenomena, that these shakings of the earth always show their effects *very much more strongly on unconsolidated strata* than on the older consolidated rocks. For this reason, an earthquake would affect these newly formed beds a hundred times more strongly

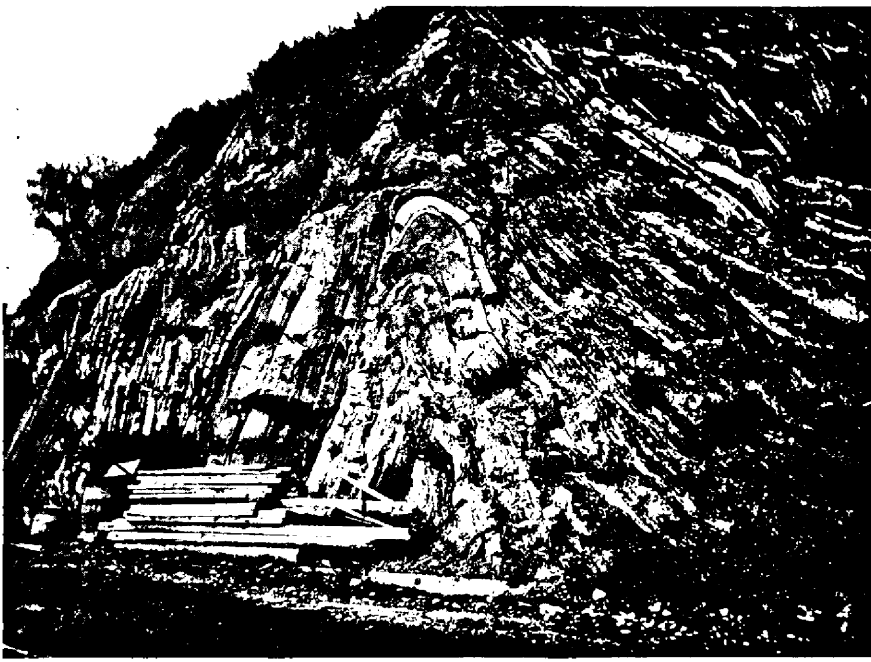

FIG. 162. Anticline in Ordovician rocks, above Levis railway station, Province of Quebec, Canada. How natural to suppose that some of the strata on the side of this cliff settled down before they were fully consolidated, crowding outward some of the strata at the foot, thus forming this neat little anticline! Obviously no great thickness of strata can be involved in this fold, for otherwise the fold would be much thicker. (Walcott, U. S. G. S.)

than it would affect rocks which were already well hardened. And we know, from the evidences so abundant in the fossiliferous rocks, that earthquakes (or *at least changes of level,* which would mean tremendous earthquakes if they were at all suddenly accomplished) *were very common while and soon after the sedimentary strata were being laid down.* Violent seismic disturbances occurring beneath deep thicknesses of sedimentary strata which were still unconsolidated, and which here and there reposed on bottom layers of unequal competence or carrying capacity, could not fail to *produce anticlines and synclines* in the upper parts of these strata, fully equal in magnitude to

anything which we actually find among our mountains, if we do not have the problem made unnecessarily large and complicated by unfounded theories about the precise order in which the respective fossils lived and were buried.

And this view of the matter would help us to understand the otherwise singular fact that practically all the *faults* which we can actually see and demonstrate in an objective way, occur in regions where the strata *are still horizontal*, or when occurring among folded strata, are as a rule *subsequent to the folding.* (W. B. Scott, "Introduction to Geology," p. 365.) Any faulting which might occur *before* the strata were consolidated would not be recorded, because not visible through these soft beds, folding even resulting in many instances instead of faulting. And although we must suppose that many profound faults and disturbances took place during and closely subsequent to the deposition of the strata by the great world catastrophe which we have postulated, yet, as we now observe them, *real faults occur* (or are visibly recorded) *almost entirely in regions where folding is absent.*

In addition to all this, we know that great masses of soft semiliquid rock have in very many instances been *squeezed out on top of the overlying strata;* and it would necessarily follow that some areas underground must be supposed *to settle to fill up the space thus evacuated.* This would account for other examples of settling and tilting of the strata. And we must remember that where a great mass of half-hardened strata a mile or so deep was tilted up on one side, so as to cause even a slight movement downward along the line of the unsupported portion, necessarily the beds at the lower side would be very much disturbed, probably even made to stand on end for a short distance.

Thus it would seem that we have now reached a rational explanation of practically all the outstanding phenomena observed in our great mountain ranges, if we will admit that *some of them* may have been in existence *before* the sedimentary strata were deposited.

CHAPTER XV

Mineral Veins and Ore Deposits

Definitions. Any natural substance having a definite chemical composition throughout its mass, is a *mineral.* Thus the *rocks are composed of minerals,* often of various mineral pieces mixed together, as granite is composed of quartz, feldspar, and hornblende (often mica). But minerals often occur in *veins,* which are breaks or fissures filled with minerals.

The term *ore* is sometimes used to include anything useful which is mined from the earth. But speaking precisely, ores should include only such substances from the earth as will *yield metals,* thus excluding coal, salt, and building stones. The more important ores are those which yield such metals as gold, silver, copper, lead, and iron. Gold usually occurs *free,* or as the *native metal.* Silver and copper also occur thus sometimes, but oftener they are found combined with other substances. Lead and iron occur only in combination. Some of the most important ores are combinations of two or more of these metallic compounds. *Sulphides* of each of these metals except gold are of frequent occurrence; but *oxides* of copper and iron are also common, and so are the *carbonates* of copper, lead, and iron.

The ores and minerals can be divided into two great groups,— those containing oxygen, and those which do not contain oxygen. They are often termed the *oxide* and the *non-oxide* groups. We have already learned that throughout the crust of the earth, in the *zone of weathering,* which extends down to the level of ground water, or the *water table,* the rocks are acted upon by the usual agencies of weathering; and here oxidation is of very common occurrence. Below this, other kinds of chemical changes go on; but "experience in mining teaches that in the upper zone the ore minerals are most likely to occur *as carbonates, sulphates, and hydrated oxides;* below this, they occur chiefly as *sulphides,* and in the case of iron as *non-hydrated oxides,* while metallic silver and copper may be also produced by the oxidation and alteration." (Pirsson.)

Occurrence. Ores may occur in the form of small particles scattered through a large mass of rock. If this mineral or ore is gold or silver, even such scattered fragments may be of sufficient importance to pay for mining it; but it is obvious that iron or lead in this scattered form would be valueless. Fortu-

nately, deposits of lead and copper and the less valuable ores have in many cases been *enriched* by accumulation or concentration, so that such an ore deposit may now be much richer than when it was first formed. The iron ores often occur in beds or large lenticular masses between sedimentary strata; but the other ores more frequently are found filling fissures or seams in the rock, such ore deposits being known as veins.

These ore deposits in veins, however, do not usually fill the entire cavity. More frequently the actual volume of the metal is only a very small part of the total mass filling the vein, the rest of the material being known as *gangue,* which may be quartz, calcite, siderite, or almost any other sort of rock. One of the most common substances associated with such mineral deposits is sulphide of iron, or *pyrite* (FeS_2). This substance is valueless, and if present in some ores, is a great nuisance, as the sulphur in it is difficult to get rid of in the process of *smelting* or reducing the ore.

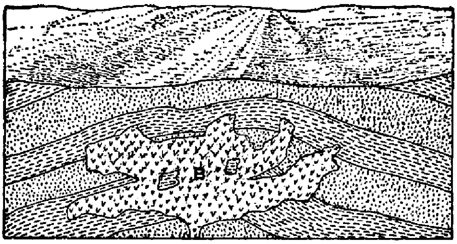

FIG. 163. Replacement ore deposit. The inclosed light areas show the ore. The suspended blocks of still unaltered limestone in the ore body show that the cavity could not have been an open one when the ore was deposited. (From "The New International Encyclopædia," by permission.)

The veins in which minerals occur are often found to run across the country for many miles, and to penetrate into the earth to depths which are beyond the reach of mining. Such great earth fissures were evidently first caused by the dislocations associated with earthquakes, and their walls are often quite straight and regular, with a more or less constant width, and a definite direction of both strike and dip. (Spurr.) The material filling such a fissure is usually quite distinct in appearance and in character from the wall of *country rock* on either side; but there sometimes occurs inside the primary vein another vein, which has evidently been formed *after* the first deposit. Most of such deposits filling veins are thought to have been made by precipitation from an aqueous solution containing the materials of the vein, more frequently a hot solution.

In other instances, the circulating waters have apparently picked up by solution the materials of a part of the rock, such as the calcite or the phosphate composing a fossil shell, and have *substituted* for this material which they have carried off some entirely different substance, such as iron sulphide or quartz. In such a case, we find an exact reproduction of the

FIG. 164. Sandstone dike in Protoceras beds (Oligocene), south of White River, South Dakota. (Barnett, U. S. G. S.)

shell or other object, looking exactly like the original, but now composed of an entirely *different material.* In a similar way, the crystals of an ore or mineral deposit may be entirely replaced by other materials which now assume the form of the original crystals. Such phenomena are termed *veins of replacement.* They occur very commonly in limestones, because the latter are readily soluble; but they occur in many other kinds of rock.

Mineral veins are found chiefly in the oldest or Archæan rocks, and in sedimentary rocks which have been much fractured or disturbed; but they are usually absent from regions of undisturbed strata. Thus mineral veins are generally associated with rocks which have been metamorphosed or which are near to igneous intrusions. Occasionally there are found fissures or veins which have been filled with sand or other sediment. Such are called *sandstone dikes* (Fig. 164), though they are not true dikes, the latter being always composed of igneous rocks. Such *sediment-filled* veins have evidently been formed during some earthquake or volcanic disturbance, when sediment has been washed into these open fissures from above, or in some instances, injected into these fissures by pressure from below.

Bedded Ores and Placers. As already mentioned, iron often occurs *in beds* which are interstratified with other rocks (Fig. 166); but manganese ore and a few other ores are also occasionally found occurring in this way. Such *bedded ores* of iron are usually found among rocks which have become highly metamorphic, and are especially common in association with the crystalline schists. Stratified beds of river gravels which contain grains or nuggets of such heavy metals as gold and platinum, are termed *placers;* and they have been formed by the

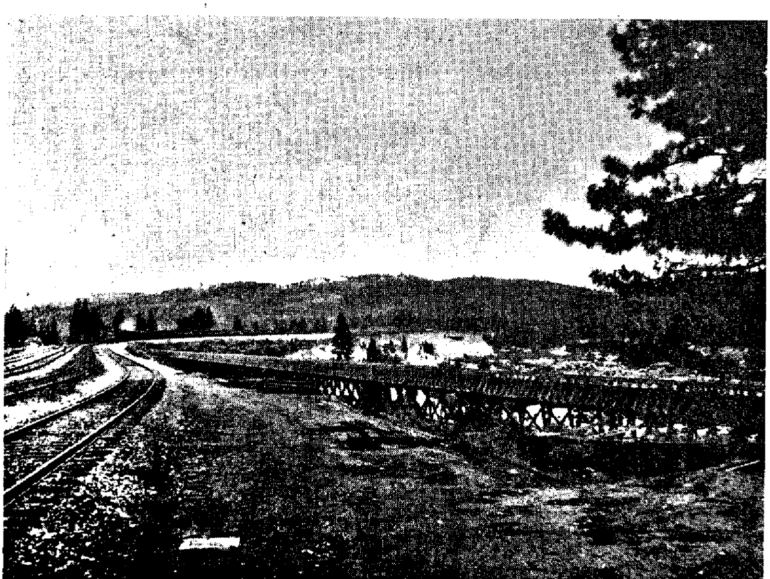

FIG. 165. View of the Tertiary gold gravel deposits, between Gold Run and Dutch Flat, California. (Gale, U. S. G. S.)

FIG. 166. Face of limonite in a mine cut, Cass County, Texas. (Burchard, U. S. G. S.)

settling and concentration of these metallic particles, which have been transported by currents of water, and which, because of their great specific gravity, have settled into pockets or depressions when the sand or gravel was deposited.

Origin of Veins. The exact process by which metalliferous veins have been produced is not clearly understood, or at least there is not a perfect agreement among geologists as to how they have been produced. Doubtless many variations in the

process have occurred. But in general, it seems evident that the contents of these veins have been *precipitated from solution* in thermal waters and vapors, by a process similar to what is now going on in connection with many hot springs. Such thermal waters must have a channel along which they flow; and as only very minute quantities of the metals are contained in these waters, large quantities of such waters must pass through a rock fissure in order to make any considerable accumulation of the ore. But the rate at which such formation of deposits may take place is quite obscure. Evidently in the long ago, while the rocks were more heated than they are now, because of the metamorphic processes which had only recently taken place, the rate may have been *much more rapid* than now in such localities; for in most instances, this formation of ore deposits is now completed and no longer in progress, though a few scattered examples of deposit from hot springs are still observed. Many speculations have been indulged in, regarding the manner in which various particular mineral veins have been formed; but while more or less plausible or interesting as speculations, they do not have the certainty of definite scientific knowledge.

Secondary Enrichment. A process known as the *secondary enrichment* of veins seems to be of very common occurrence. Many different kinds of veins may be enriched in this way; but the process may be illustrated by the way in which it occurs in the case of gold and iron.

The part of any mineral vein above the level of the ground water is usually much affected by the processes of weathering. Below the level of the ground water, or the water table, gold is often found within crystals of pyrite, or iron sulphide. But above the water table, the pyrite has disappeared, leaving the free gold scattered as minute threads and grains among a mass of partly shattered quartz, the latter stained rusty red or brown from the iron oxides remaining after the pyrite has been leached out.

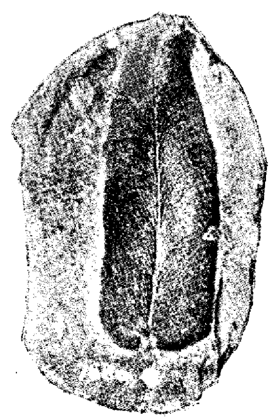

FIG. 167. Concretion of clay ironstone split in two, showing inclosed impression of fossil fern (Neuropteris). From Mazon Creek, Illinois. (Photograph by B. Hubbard, from specimen in Columbia University.)

Pyrite, under the action of air and water, is slowly weathered and changed into ferrous sulphate, which is soluble, and which in turn is changed by oxidation into limonite, and sulphuric acid is set free. This

limonite often accumulates or becomes concentrated in the form of sheets or beds, and is called *gossan* or *iron hat* by the miners of England.

As there are already many sulphides below the level of ground water, and as the sulphides above this level have become oxidized, the latter are carried downward in soluble form and then turned again to other sulphides just below the level of the ground water, forming *secondary* sulphides, which are often much richer than the portions still deeper in the earth, since they represent a more concentrated stage of deposit.

Some of the ores of lead and zinc, often found occurring in the joints or bedding planes of limestones, may have been formed in this way.

Doubtless a great variety of methods have been employed by nature in producing the numerous ore deposits; for the depths of the earth are an immense chemical laboratory, and these processes of chemical change are still going on underground. And it is not at all surprising that we can not always be sure of the exact method by which certain changes have taken place.

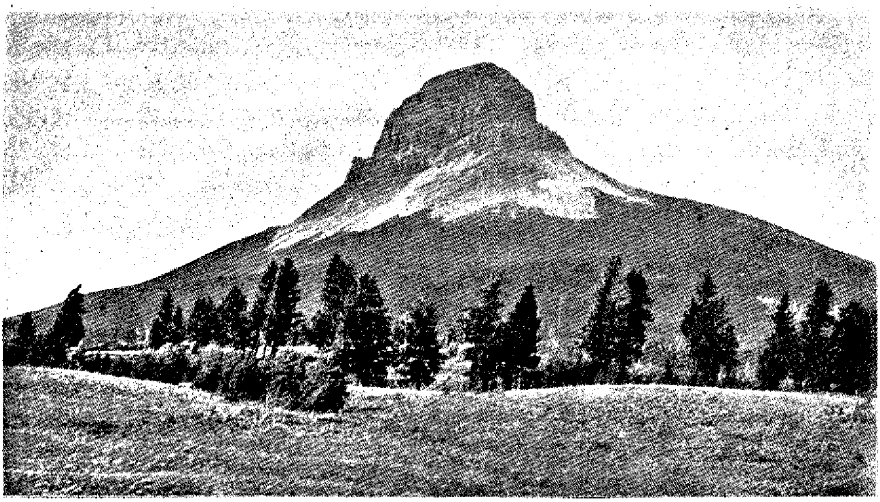

FIG. 168. Crowsnest Mountain, from near Coleman, Alberta. The jointed, precipitous part of the mountain is composed of Paleozoic limestone, resting on Cretaceous sandstones. This mountain has an elevation of 9,125 feet, or about 4,800 feet above the valley. It is situated some twenty miles west of the front range of the Rockies at this point. According to the popular theory, all this region of Paleozoic strata was pushed bodily over on top of the Cretaceous.

Part IV — Stratigraphical Geology

CHAPTER XVI

Classification

Introduction. As science has been called classified knowledge, the classification of the results attained in geology constitutes an important part of the subject. As this science has been extensively studied for more than a century and a half, different systems of classification may well be supposed to have been in vogue during this time. There has been a constant endeavor to arrange the rock deposits of the world in *some sort of chronological order* for the world as a whole — a real cosmogony. At first, such a chronological arrangement was based chiefly on the minerals or the *lithological* character of the rocks. But about a hundred years ago a system was devised of arranging the stratified beds of the earth in an alleged chronological order based primarily on the *types of fossils* found in the rocks. A more minute study of the history of this part of the science will be given in a later chapter; and a discussion will

also be given of the value of this chronological or historical arrangement. In this chapter, we must be mainly concerned with the common methods employed in classifying the rocks, contenting ourselves with a mere outline statement of some of the principles which should govern us in making such a classification.

As we have so often pointed out, geology deals with the earth's past, and is thus historical in character, and it is principally concerned with the problem of *how* and *when* the various geological formations took place. Moreover, the geological

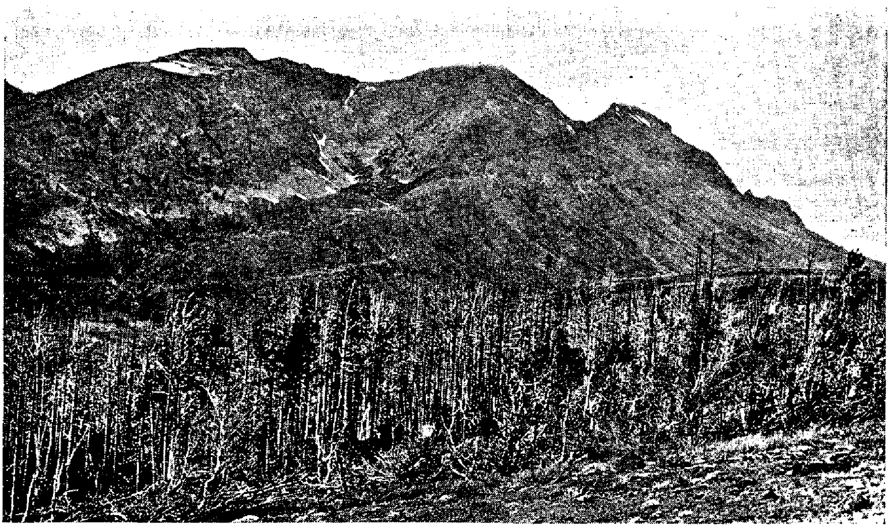

FIG. 169. Glacier National Park. Summit Mountain from the southwest, showing the contact line on the slope, Algonkian resting on Cretaceous, apparently in conformity. (Stanton, U. S. G. S.)

work recorded in the rocks evidently *took time,* and was not all done instantaneously. The question in this connection is, *How much time?* and, *How long ago?*

The Time Problem. Dealing with this latter point first, we can only say that remains of numerous *living species of animals,* including probably *man,* are now known to have been involved in every great class of geological change. The commonly accepted theory of evolutionary geology would have us believe that only certain types of life existed in the earlier ages of the world, and that afterwards these disappeared, and other entirely different types made their appearance, flourished for a time, to be in turn succeeded by still different groups. But as the author has pointed out elsewhere ("The Fundamentals of Geology," *passim*), all this is *merely a theory,* and is now

Fig. 170. Cliffs of Mount Gould, Glacier National Park, Montana. Algonkian. These rocks rest on Cretaceous. (Willis, U. S. G. S.)

definitely disproved by a large number of recently discovered facts. It follows that we do not have as yet any method truly scientific by which the many various fossils contained in the rocks can be arranged in a true historical order. Accordingly, we are compelled, in the present state of our knowledge, to regard all the species of plants and animals now found as fossils as having probably *lived contemporaneously in an older state of our world.* And while it would be absurd to say that all the great geological changes recorded in the fossiliferous rocks occurred at once, yet it is impossible to say that any of these fossils *lived before other kinds of plants and animals, or before man himself was living on the earth.* This much is scientifically certain; and it is about all that we are scientifically certain of in the complicated condition of this very large subject. Perhaps before we get through with the study of these fossiliferous deposits, we may have arrived at more definite knowledge on various other points; but it will not do for us to be dogmatic about these matters here at the outset.

As to how much time was occupied in the geological changes, we can speak only in the most general terms. In any undisturbed vertical section, the lower strata were certainly laid down *before* those on top; and this gives us a *local time scale.* But such a local chronology is of no value, unless we can *correlate* the events occurring in this locality with other events which are recorded in other parts of the world. At present, we do not have any basis for such correlation which will bear the rigid inspection of exact science. But from a study of the rocks in a large way, it appears that most of the *mountain making* occurred after the greater part of the strata were deposited. The erosion of the valleys, and the deposits made by the rivers in the form of their *high terraces,* came next in order; and such erosion and the formation of other river deposits is still going on in a greatly modified way. Furthermore, it seems quite evident that the so-called *"glacial" deposits* (or more properly, the *drift*) were spread out *after* probably all of the true fossiliferous strata were formed, and even (it may be) after much of the mountain making had been done. Much the same statements may be made regarding the *old shore lines* which encircle all the continents. This much in the way of a chronology or history of the events recorded in the rocks is about all that we can state with certainty just at present.

On the hypothesis of a universal Deluge, we would merely have a sudden and awful event, so far as its beginnings are concerned. According to the Bible account, the Flood prevailed over the whole earth a little more than a

year, with much additional time before a complete readjustment was effected. Doubtless the full recovery from it occupied much more time than the event itself. On this hypothesis, we might well suppose that the completion of the mountain making, and the spreading out of the drift over Western Europe and Northeastern America, may have occurred years or even centuries after the other geological work was done, and after practically the present land and ocean boundaries had been established.

FIG. 171. Surface of fossiliferous limestone slab, one twenty-fifth natural size. Upper Ordovician. (Photograph by Bassler.)

But whether we accept this hypothesis of a universal Deluge or not, the chronology of events as outlined in the next to the last paragraph preceding is definite and scientific enough, so far as it goes. Thus on the basis of any truly scientific study of the rocks, *there are but two great ages known to inductive geology,* and these two ages we may well term the *geological proper* and the *recent.* However, the time limits of each of these are entirely unknown from any mere geological investigation. No system yet devised of reading absolute time from the rocks has the slightest scientific value. The length of time which was occupied in quietly *accumulating* the vast mass of

organic and inorganic *materials* which were subsequently taken up by the waters and rearranged as we now find them, is wholly beyond scientific conjecture. And if we deal with this subject by the methods of natural science alone, the length of time *since* these great earth changes occurred can be only very roughly approximated.

STRATIGRAPHICAL GEOLOGY treats of the kinds and distribution of the fossil-bearing strata; the kinds of fossils found in them; and a classification of these rocks into appropriate groups based on the fossils which they contain. It also includes the larger lessons to be learned from the conditions and circumstances in which we find both the strata and their fossil contents. This part of the general subject of geology used to be called "historical geology," which was a decidedly objectionable term, because the historical distinctions which were thus dealt with were based on a purely artificial arrangement of the rocks, and these historical distinctions we have now found to be wholly unscientific and fanciful.

Principles of Classification

Merely a Taxonomic Series. Although all the present systems used in classifying the plants and animals of our world, living and extinct, are more or less fanciful and unnatural, because of the dominating theoretical prejudices under which these classifications have been arranged, yet, in most cases, the deviations from a more natural system are not of sufficient importance to occasion any serious objection to their use in such a work as this. The geological series also represents *merely a taxonomic series* of the life of the ancient world; and like any modern taxonomy or classification, it is a purely conventional arrangement for *educational convenience,* and has been based on the prevailing ideas of the structural relations between the different groups of the fossils. The dominant idea, of course, in the minds of those who arranged the geological series, was the evolution theory regarding the development of life, and this theory is embalmed in the arrangement which was thus made. Repeatedly, during all the history of the science, the recognized order in which the fossils *ought* to be placed, has been subject to readjustment; and such readjustments are still of frequent occurrence, as a means of bringing the geological order of the fossils into more apparent agreement with what is recognized as the true organic development. Yet, in spite of all this, it will be possible for us to handle this present arrangement and take it at its face value, so far as a mere classification of the fossils is concerned. But we must constantly endeavor to *forget the time-values* which have so long been associated with this arrangement. Hence, though we shall continue to use the ac-

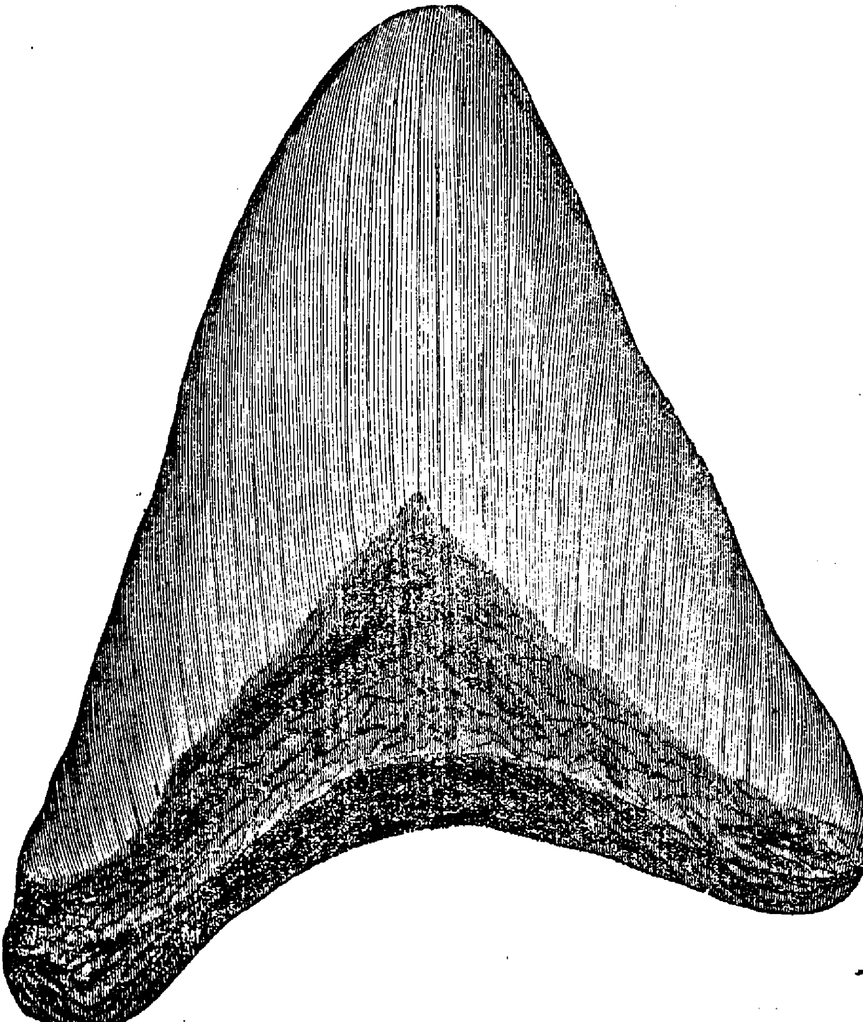

FIG. 172. A shark's tooth, natural size, from North Carolina.

cepted geological classification of the stratified rocks, we must at the outset *repudiate most emphatically any idea of a time-value attaching to the various geological names.* In many ways, the current system of geological classification seems absurd for those who realize the fanciful — we might almost say, the farsical — character of the reasons behind such an arrangement; but it has been thought best for the present to continue the popular classification, because of its almost universal acceptance and its familiarity in the minds of most intelligent people of the present day.

Criteria. The following are some of the leading principles which must constantly be borne in mind while studying the fossiliferous deposits:

1. The larger divisions of the rocks are named from the dominant types of life which they contain. These larger divisions are termed *groups*. Thus we have the Mesozoic group, which is often called the group of reptiles (formerly the "Age of Reptiles"), because the dominant type is reptilian. The following words from standard authorities will make this point clear:

"The primary divisions of the geological time-scale are, as we have seen, based on the changes in life, with the result that *fossils alone* determine whether a formation belongs to one or the other of these great divisions."— *Grabau, "Principles of Stratigraphy," p. 1103.*

But the *systems*, or the subdivisions of the groups, are likewise based just as wholly on the types of life which they contain, as will appear from the following:

"These systems, although actually arbitrary groupings of the stratified rocks of particular regions, have come into common use as the primary divisions of the rocks whenever chronological sequence is considered. In describing any newly discovered fossiliferous strata in any part of the earth, the first step to be taken, in giving them a scientific definition, is to assign them to one or other of these systems upon evidence of the fossils found in them. *The character of the rocks themselves, their composition, or their mineral contents have nothing to do with settling the question as to the particular system to which the new rocks belong. The fossils alone are the means of correlation."— H. S. Williams, "Geological Biology," pp. 37, 38.*

2. The stratified rocks comprise an indefinite number of shales, limestones, sandstones, and conglomerates; but these mineral or lithological characters *are of little or no assistance* in identifying, classifying, or naming the fossiliferous rocks, as almost any kind of life is likely to be found in any of these types of rocks indifferently. That is, mineral and lithological characters, though of great value in any limited locality in tracing out continuous strata, are of little value in identifying or classifying rocks in any large way, and are quite generally ignored; though in some instances, it has been found that particular types of life accompany certain textures of deposits.

Where some peculiar type of rock is spread out over a large region, it may be often identified in disconnected localities by its structural characters, entirely without the aid of fossils. Thus the remarkably interesting Paleozoic limestones of North-

ern Montana and Southern Alberta are readily recognized, even at great distances, by their characteristic jointed structure, often comprising the rectangular, cathedral-like tops of such mountains as Chief and Crowsnest. Thus in this subordinate sense, lithological characters are useful in identifying and classifying rocks.

But it must also be remembered that "the same bed often changes its character from a sandstone to a shale, or from a shale to a limestone or a conglomerate, or again to a sandstone" (Dana), within a few miles, or even within a few hundred

FIG. 173. Unconsolidated Pennsylvanian clay and sandstone resting on St. Louis limestone (Mississippian), southwest of Colchester, Illinois. (Hinds, U. S. G. S.)

feet. And it is also true that when distinctly *different* types of fossils are found in different parts of what seem like *the same set* of connected strata, some way will always be discovered or invented to account for this apparent connection; for fossiliferous evidence is always considered paramount to all other evidence whatever.

3. The condition of a rock as to its *degree of solidification or crystallization* is no guarantee as to the kinds of fossils which it may contain. Any type of life, even what used to be called the very "youngest," is likely to be found in crystalline or metamorphic rock, as old in appearance as any on the globe. The Cambrian beds near Petrograd, in Russia, and in Wisconsin, are as young in appearance as some recent river deposits, consisting, as they do, of clays that are scarcely indurated, and sands still incoherent (Figs. 173 and 174). Conversely, many

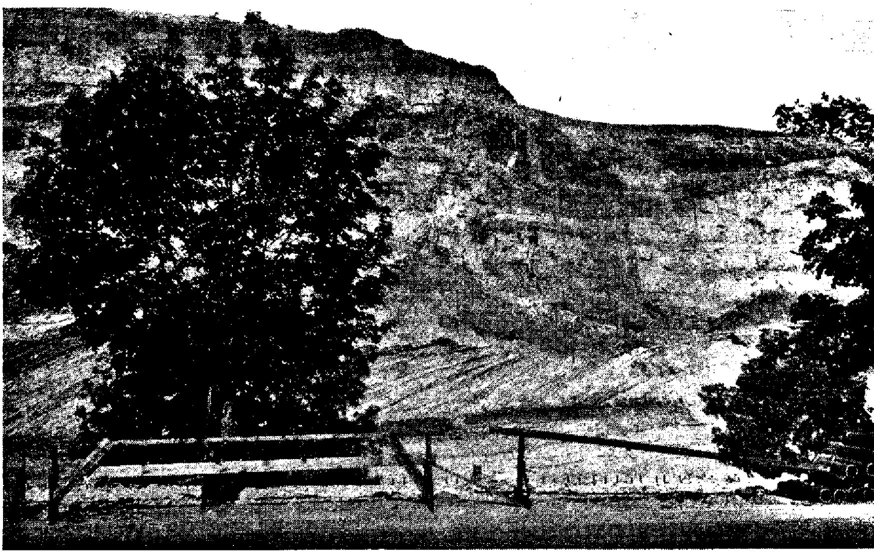

FIG. 174. Cretaceous sand and gravel (unconsolidated), looking east from Sixteenth Street, Washington, D. C., just above Florida Avenue. (Butts, U. S. G. S.)

beds containing "young" fossils, and therefore classed high up in the geological series, are contained in rocks as old-looking as any on the globe. The Eocene schists of the Alps, and the Eocene marbles of the Himalayas, are as highly metamorphosed and crystalline as even the oldest of the Paleozoic rocks; and the same may be said of many of the "young" Tertiary rocks of the Coast Range of California. The Nagelfluh of Salzburg, Austria, is a highly consolidated conglomerate, although it is classed as Pleistocene; and a similarly solidified deposit of Pleistocene is to be seen near the railway station at Lewiston, on the Niagara River.

4. "A stratum of one era may rest upon any stratum in the whole of the series below it." (Dana.) Not only so, but it may even rest *conformably* upon it, giving every physical evidence that the one followed the other in quick succession. Thus the Cretaceous may rest in apparent conformity on the Devonian, the whole of the Jurassic, Triassic, Permian, and Carboniferous being wanting, as occurs around Lake Athabaska for some 150 miles. At Ust-Waga, on the Dwina, in Northern Russia, the Pleistocene shell beds rest in "absolutely conformable superposition on the horizontal Permian sediments" (Suess), while many similar examples could be given elsewhere (Fig. 422). In such cases, there is nothing even in the way of erosion to give a hint of the alleged long ages of time intervening be-

tween the successive beds. Judged by these localities, these alleged ages never existed.

5. But the exact reverse of these conditions may also occur. That is, Cambrian or Silurian or Devonian beds may be found not only above Triassic, Cretaceous, or Tertiary, but they may be found in this position *with just as much apparent conformability,* giving every physical evidence, over vast areas, of having been deposited in the order in which we find them. Chief Mountain, Montana, and Crowsnest Mountain, Alberta (Fig. 168), are examples of Paleozoic limestones and quartzites resting in apparent conformability upon Cretaceous shales. Indeed, the whole of the Glacier National Park is composed of Paleozoic rocks resting in a perfectly normal way on the Cretaceous; for on all sides of this large area, the Cretaceous beds run under the Paleozoic mountains almost horizontally, though of course it would be unreasonable to expect to find true conformability throughout this area. Many similar examples from other parts of the world will be given in a later chapter.

6. Where we can not prove, by physical evidence, that the strata have been disturbed, the obvious *order of superposition,* as shown by a vertical section or by outcrops of inclined strata, *ought to be regarded as the true historical order for the locality.* No theories concerning a supposed "normal order" of the fossils

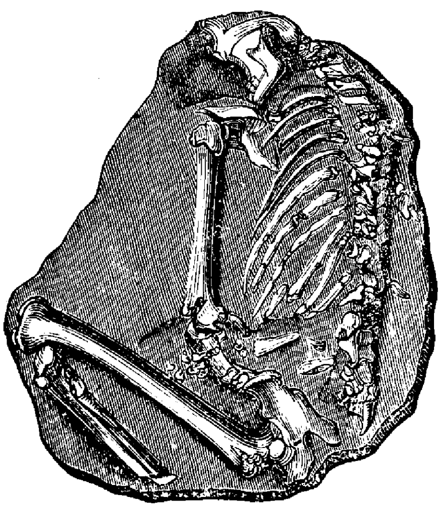

FIG. 175. A fossil skeleton of man from a shell-rock of Guadeloupe, West Indies. "It is the remains of an Indian killed in battle two centuries since; and the rock is of the same kind with that which is now forming and consolidating on the shores." (J. D. Dana.)

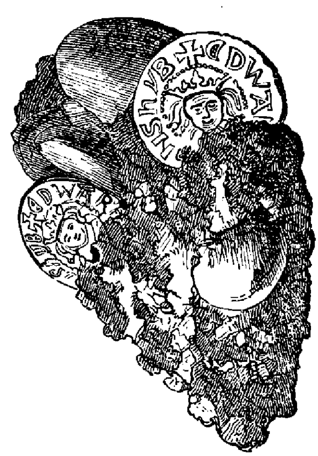

FIG. 176. "A *coin-conglomerate* containing silver coins of the reign of Edward I, found at a depth of ten feet below the bed of the river Dove in England." (J. D. Dana.) Both of these examples illustrate how rapidly rock tends to harden under certain conditions.

should be allowed to warp our conclusion as to the historical order of events in any particular locality, as read from the local order of superposition. Physical and natural evidence should always have the right of way over theoretical evidence of every kind, and especially over fossil evidence. Fossil evidence (theoretical) ought to be regarded as utterly worthless when confronted with a physical fact.

But as physical or stratigraphical evidence is the only kind of evidence competent to testify in reference to the relative ages of two contiguous strata, even this evidence is of *only local value,* pertinent only so far as the beds themselves extend. We no longer believe in the onion-coat theory, since we know that

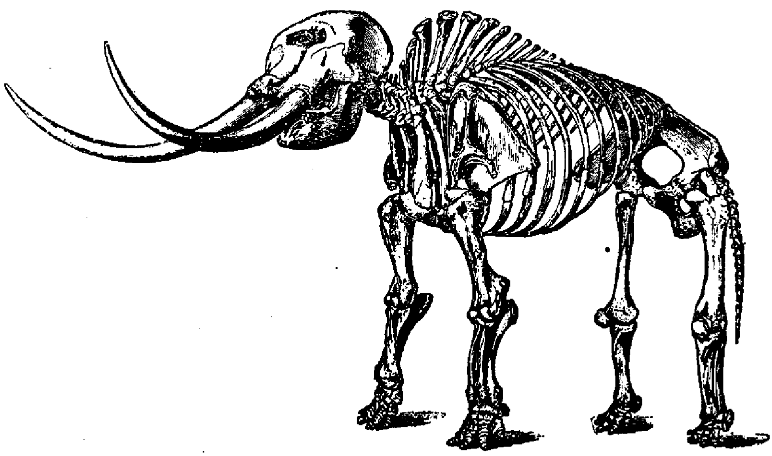

FIG. 177. Skeleton of *Mastodon giganteus.*

all sedimentary beds are of limited extent; and hence the order of the beds in one locality can never be allowed to dictate the relative order of the beds in another locality with which they are not in stratigraphical relationship. And onion coats of fossiliferous strata are as absurd and unscientific as onion coats of a lithic or a mineralogical character.

7. But when we decide that one bed is older than another, on stratigraphical evidence, it is obvious that we can not say *how much older* it is. Even an angular unconformity between the two may mean only a sudden earthquake and the erosion of the tilted (unconsolidated) strata by submarine currents; and all this may have taken place deep beneath the waters, within a short space of time. Or if these upturned and eroded strata were elevated above the waters, the time interval represented may be only the interval between two successive tides, if the

lower strata happened to be soft and unconsolidated when the disturbance took place. To explain every angular unconformity, or any angular unconformity, as due to slow elevation above the sea and then to ordinary subaërial erosion and base-leveling, is *pure assumption,* and has no finality or certainty about it as a scientific fact.

A very *marked break* in the fossils between two consecutive beds is always interpreted as implying a very great lapse of time. But if we do not deny the possibility of *biological zones and districts* in the olden time, but admit that diverse faunas and floras may have existed *contemporaneously* in separated localities, just as they do to-day, a marked break in the fossils of two successive beds may mean *only a change in the currents,* or the mere difference between the ebb and the flow of the tide, bringing into a vertical relationship of position distinct faunas or floras which had been living in a geographical relationship more or less distance apart.

Hence, although an angular unconformity or a marked break in the fossils between two contiguous layers of the strata shows a distinct time interval, yet this interval *may not have been long.* We may assume that it was a long interval; but this would be a pure assumption, with no warrant in the way of strictly scientific evidence.

8. More common sense and less theory needs to be used in stating the *total thickness of the strata* found in any particular locality. It is often the case that strata are added together to make an absurd total, with no more justification than there would be in adding together the total thickness of the scales on a fish from the tail to the head, because they are found to overlap, or in adding all the shingles on the roof of a house. The report of a total thickness of the strata in any particular locality which greatly exceeds what can be physically demonstrated in some vertical section, ought always to be regarded with suspicion. Such an excessive thickness is usually built up out of theory; and geologists need to be especially mindful of the rule of inductive evidence that *the inference from one theory must never be treated as the substantive foundation for another theory;* or as it is commonly stated, we must never *base an inference on an inference.* If this rule were always followed, there would be much less ink and paper wasted at the government printing office and at other printing establishments.

Groups, Systems, Formations. As has been already stated, the larger divisions of the strata, or the *groups,* as classified in the geological series, such as the Paleozoic, Mesozoic, and Ceno-

zoic, *are based wholly on organic factors,* and are merely ideal divisions entirely independent of stratigraphical considerations.

The next set of divisions, or the *systems,* such as the Cambrian, Ordovician, Silurian, Devonian, etc., were originally based chiefly on field evidence, or stratigraphical evidence. But with the progress of the science, and with the assembling of vast numbers of formations gathered from widely separated localities to make each of these systems complete, these systems *have in turn become merely ideal or imaginary groups,* based wholly on organic or evolutionary considerations. The inferior subdivisions, called variously *stages, zones, horizons,* or simply *formations,* which have chiefly local geographical names, still retain much more of their original stratigraphical features; and it is often extremely difficult or impossible to assign them to a definite place in one of the higher divisions, since they may contain typical groups of fossils found in two or more. This difficulty arises from the arbitrary character of the larger divisions, which are based not on stratigraphy, but on theoretical relations between the types of life, *stratigraphy and these taxonomic relations being wholly incommensurable;* just as it would be, in fact, to try to measure music by the square yard, or beauty by the gallon. These difficulties arising from an attempt to classify the stratigraphical formations according to an artificial scheme of life, are continually multiplying with a more careful and detailed study of the rocks in new localities, such as Australia, China, and Africa; *but even these subordinate divisions are fast assuming a purely abstract or constructive character,* as various scattered formations are assembled and grouped together under some common name.

There can be no serious objection to the following rule put forward by the United States Geological Survey to determine the method of defining and identifying the *formation* as the stratigraphical unit:

> "As uniform conditions of deposition were local as well as temporary, it is to be assumed that each formation is limited in horizontal extent. The formation should be recognized and should be called by the same name as far as it can be traced and identified by means of its lithologic character, its stratigraphical association, and its contained fossils."

But we must ever bear in mind that when such a formation has thus been worked out in some definite locality in the field, the *correlation* of this formation with other similar formations on the other side of the globe (it may be), or its assignment to a definite place in the long series of successive life-forms, is not the work of the field, but of the laboratory or the library, and

is based wholly on theoretical considerations regarding an imaginary succession of life. Thus this correlation with other distant formations, and its assignment to a place in the hypothetical ladder of life, are both *purely arbitrary and artificial acts,* and their results have only a constructive existence, with only such values as are possessed by the theories on which they are based.

Methods. As worked out in the field, the methods employed are logical and scientific enough *for the local conditions only,* or until a correlation is made with distant localities, or until speculative theories regarding the time relationships of organisms are dragged into the work. Dana has thus stated the method:

"In the study of a new region it is necessary at the outset to make arbitrary subdivisions of its formations, such as may seem most convenient and natural, and give them local names. These names have at first only a notebook value. When the relations of the beds to those recognized in other regions have been ascertained through fossils, the facts begin to take their place in the general geological history of the country; and should the correlation be complete, the local names may give way to those generally accepted elsewhere."—*"Manual," p. 405.*

Difficulties. But in multitudes of cases, it has been found difficult or impossible to correlate exactly these newly studied beds with the classifications recognized elsewhere. In such instances, the local names are retained and are used *as new local centers of crystallization about which other neighboring strata may be assembled,* as in the case of the Laramie of the Rocky Mountain region, which are partly Cretaceous and partly Tertiary, or the Rhætic formation on the Rhine River, in Europe, which can not with certainty be assigned to either the Triassic or the Jurassic, or the Morrison beds of the eastern front of the Rockies, which are partly Jurassic and partly Cretaceous. Literally hundreds of similar examples might be given.

Such a failure on the part of a formation to fit into its prearranged pigeonhole, is often dodged or disguised by another method which is not so candid or so justifiable. Also this method is employed when species are found in kinds of rock where they are not at all expected, and where, according to the prevailing theories, it is quite incredible that they should be found. In such a predicament, the not very honorable expedient is resorted to of *inventing a new name,* specific or even generic, for these inconveniently found fossils, to disguise or gloss over the strange similarity between them and the others which have already been assigned to wholly different formations. As remarked by Heilprin:

"It is practically certain that numerous forms of life, exhibiting no distinctive characters of their own, are constituted into distinct species for no other reason than that they occur in formations widely separated from those holding their nearest kin."—*"Geographical and Geological Distribution of Animals," pp. 183, 184.*

Note.— Who is competent to go through the 13,000 described "species" of living fishes, the 22,000 mollusks, the quarter of a million arthropods, with the uncounted echinoderms, brachiopods, and cœlenterates, and weed out those that are mere duplicates but listed as distinct species or genera because of our ignorance or our disregard of the possibilities of Mendelian variations in these groups, or because their fossil representatives are found in "widely separated" formations, and the traditional theories forbid that they be identical, although they may look exactly alike? It seems a hopeless task; but the tendency of the best zoölogical work is strongly in this direction. These reformed methods, however, have not yet been adopted among the paleontologists.

What the Terms Mean. In the following enumeration, we have adhered to the current nomenclature as nearly as possible, even at the expense of retaining some names which are decidedly objectionable because of their etymological meaning, and which may ultimately have to be discarded when a true inductive geology has become more firmly established.

However, we all understand that by *Cambrian, Devonian, Triassic,* and the other names of systems, we mean only *those rocks which contain certain kinds of fossils.* And as most of the names of the systems and the divisions are geographical in origin, they are, in themselves, neutral as to theory, and will probably endure the test of time. In this respect, they conform to the standard set by Huxley in his essay on "Homotaxis," where he demands names expressing merely *"similarity of serial relation, and excluding the notion of time altogether."* The names of the great groups, "Paleozoic," "Mesozoic," and "Cenozoic," as well as the name "Tertiary," are decidedly objectionable as embalming the fancies of an outgrown hypothesis, and will some day have to give place to others, that express no theory as to age or origin. But they have been retained here, as Dana says of "Tertiary," "simply because of the convenience of continuing an accepted name." Chemistry and astronomy still carry many names surviving from the old fooleries of alchemy and astrology; and perhaps geology can hardly expect to fare much better.

The Groups. In most places, we do not have to go very far down into the earth before we come upon rocks which contain no fossils and which we have every reason to believe never contained any. Whether we assume the evolution theory, or assume the creation hypothesis, and its corollary, a world Deluge, we must always come, sooner or later in our descent into the

earth, upon these *primary or original rocks,* which we may suppose to have existed before the fossiliferous beds began to be laid down. They have gone under many names, and of late they have been subdivided elaborately into alleged successive ages. They are usually highly crystalline or metamorphic, but there is no antecedent reason why we must always expect to find them in this condition. These lowest and really *oldest* rocks we shall agree to call the *Archæan group.*

There is always a marked unconformity between the Archæan rocks and the strata lying upon them.

The next great group of rocks contains a great variety of the lower forms of life, such as mollusks, crinoids, corals, trilobites, also numerous low types of fishes, and the preserved remains of a luxuriant vegetation of a low or "primitive" character, as found in our greatest coal beds. These rocks also contain some amphibians and reptiles of inferior tribes. This group of rocks is called the *Paleozoic group.* Or, to turn the statement around the other way, so as to accord with the actual methods employed, it would be more exact and scientific to say that *any rocks found to contain such types* of life as we have just spoken of, *are always classed with the Paleozoic group,* no matter whether they look old or young, and no matter what their stratigraphical relationship with any other group or set of strata.

On the hypothesis of a world Deluge, it would not be necessary to assume that all the beds of this group were rearranged by the waters of that turmoil. Many of them may be regarded as still in their original positions.

The next great group of the fossiliferous rocks is quite distinct from those already mentioned as to the contained types of life, there being few species common to the two groups. The dominant type of life in these is the *reptilian,* so much so that these rocks were formerly assigned to an "Age of Reptiles." But this group is now better known as the *Mesozoic group* (mesozoic=*middle life*). Or, to make additional remarks similar to those already made regarding the preceding group, any strata which contain the typical fossils of this group would on that account be assigned to this group, no matter what their mineral or lithologic texture, and no matter what their stratigraphical relation to any of the other rocks.

Last of all, we have a great group of rocks consisting of a great variety of textures and a still greater variety of fossils. These rocks contain few of the great reptiles, and few of the types of life assigned to the other groups. Instead, they contain the remains of *land quadrupeds or mammals in great numbers*

and in amazing variety, with the higher orders of plants and the more "modern" types of invertebrate life. Some scanty and ambiguous remains of man are assigned to the "uppermost" or "latest" part of this group. These rocks comprise the Cenozoic group. That is, any rocks which contain the bones of the great land quadrupeds or the shells of certain of the "higher" invertebrates, would because of these very facts be assigned to the *Cenozoic group.* And this definite and positive assignment would be made in spite of any appearance of great antiquity which they might show, or in spite of even direct and positive proof of Mesozoic or Paleozoic rocks stratigraphically above them. If lithologic texture and stratigraphic position agree with the fossil evidence, all right and good; they are then regarded as "assisting" in the classification of the rocks. But if lithologic texture and stratigraphic position disagree with the fossil evidence, so much the worse for the texture of the rock and its apparent position. Such is the universal method of reasoning employed in this classification.

Illogical Methods. A card catalogue or index is a very useful thing in a library. But it would strike us as highly absurd if some antiquary should come along and solemnly assure us that this card catalogue showed the real history of the order in which the books listed had been published. Suppose he should affirm that all the books listed under A and B had been issued first, while those under X, Y, and Z had been issued last. Would we not think that this antiquary ought probably to be put into some institution for his own protection, if not for the protection of the public?

But the geological classification as currently taught, based on the grade of fossils contained in the various rocks, is just as purely artificial as the card catalogue of a library, and has no more time-value to its subdivisions. It is *merely a convenient working classification,* that is all, something to help us to name and handle the numerous fossiliferous deposits in different parts of the world. It has been made a fetish, and evolutionary theories about the development of the various types of life have been allowed to take possession of it. *But they do not own it,* and we who have had our eyes opened regarding the folly of trying to tabulate all the rock deposits in a serial order according to the grade of fossils they contain, *can still make good use of this classification,* even though we have discarded the traditional time-values so long associated with these systems.

On an average, probably the Cenozoic rocks are oftener unconsolidated than are those classed as Mesozoic or Paleozoic.

Since the Archæan group of rocks contains no fossils, it can not be subdivided in quite the same way as are the other groups.

It has its own system of subdivision, which will be mentioned later. But each of the other groups is subdivided into systems, and these again into series, and still again into other subdivisions known by various names, sometimes called zones or horizons, or simply *formations*.

The following tables will represent these divisions and subdivisions conveniently for the eye of the student.

CLASSIFICATION

Group	System	Series	Dominant Type of Life
Cenozoic	Quaternary or Post-Tertiary or Pleistocene	Recent Terrace Drift (Glacial)	Man
	Tertiary	Pliocene Miocene Oligocene Eocene Paleocene	Mammals
Mesozoic	Cretaceous	Upper or Cretaceous Proper Lower or Comanchean	Reptiles Conifers and Palms
	Jurassic	Upper (Malm) Middle (Dogger) Lower (Lias)	
	Triassic	Upper (Keuper) Middle (Muschelkalk) Lower (Bunter Sandstein)	
Paleozoic	Permian	Upper Lower	Amphibians and Coal Plants
	Carboniferous	Pennsylvanian Mississippian	
	Devonian	Upper Middle Lower	Fishes and Insects
	Silurian	Upper — Monroan Middle — Salina Lower — Niagara	Invertebrates
	Ordovician	Upper — Cincinnatian Middle — Champlainian Lower — Canadian	
	Cambrian	Saratogan Acadian Waucobian	
Primary or Primitive	Algonkian Archæan		Few Fossils or None

The geological series, or any subdivision of it, is always *read from the bottom upward,* in accord with the supposition that the first part of the series is farther down in the earth than are the other parts of the series. This is not necessarily or always the case; but one may as well get accustomed to this order as to the reverse.

The student should not be misled by the appearances given in such tables as these, of the strata piled one above another in a regular order of superposition. No fact in the whole science of geology is more necessary to be borne in mind than that the rocks *do NOT thus occur* in a single case anywhere on earth. Parts of two or three consecutive systems may occasionally be found in a locality together in this relative order; but *parts of two or three of the systems* are about as much as are ever found together. Moreover, there is a great law regarding the order and positions of the strata, which will be shown in detail in a subsequent chapter, and will be illustrated in many ways with numerous examples, this law being known as the Law of Conformable Stratigraphic Sequence. This law says that —

Any kind of fossiliferous rock, "young" or "old," may be found conformably on any other kind of fossiliferous rock, "older" or "younger."

If the student will bear this great law in mind, he is not likely to be misled by any representation of these various types of rocks in a regular successive series.

Geologic maps are often published which show the distribution of the different fossiliferous rocks. As will appear in a later chapter, any one of these great systems or series of rocks may be found resting upon the Archæan; also any one of them may be found at the top of the ground, and may constitute practically all of the surface rocks of any particular locality, with or without other fossiliferous rocks below. A geological map is made to represent the kinds of fossiliferous rocks *appearing on the surface* in various localities, usually disregarding the soil and loose materials on the top of the ground.

Distribution. Thus whenever we speak of the distribution of a certain kind of rocks, we mean that these rocks are at the surface throughout a certain region, disregarding the loose soil on top, and even disregarding what are known as "drift" materials, whenever such occur. But according to geological custom, a formation is often said to be distributed over a wide region, when its existence over much of this region is *only inferred from the dip* and other characters of the beds which outcrop here and there, and which are supposed to be continuous deep beneath other surface deposits. In some instances, this principle is legitimate enough; but it must always be used with caution, as it always involves the risk of mistakes; and it is sometimes used in a way that does not carry any conviction as to its correctness, to affirm the continuous extension of deep-lying strata between two or more widely separated exposures.

CHAPTER XVII

Fossils and Their Uses in Geology

Historical Sketch. Many centuries ago it was observed that fossils resembling the shells found in the sea are to be found far inland, often high up on some mountain side. Among the ancient Greeks, some of the wise ones attempted to explain these fossils as the result of a natural plastic force inherent in the earth itself. About the fifteenth century, when the mind of man was awaking from the slumber of ages, there was much controversy about the origin of fossils. The most common explanation at that time was that the fossils are mere mineral concretions, mere freaks of nature — *lusus naturæ,* as they were often called. Others asserted that they had been formed in the soil under the magic influence of the stars. Still others declared that they must represent plants and animals which were once alive on the earth, and that had been buried at the time of the Deluge, which was regarded at that time as a real event which had overtaken the world and which had destroyed most of the plants and animals then living upon it.

This last view was finally formulated into an argument of more or less scientific character, and was called the "diluvial theory." This opinion regarding the fossils was held by many scientists of national reputation down until the early part of the nineteenth century.

Throughout all the Mediterranean countries, there are deposits which contain fossils in such vast numbers as could not fail to arrest the attention of all inquiring minds. Among the Greeks and the Romans, there were many who explained these fossil deposits as having been due to the various vicissitudes through which the earth had passed; and based on this view, the theory grew up that there had been many successive cataclysms and re-creations of plant and animal life. This latter view maintained its position in the world alongside the diluvial theory until about the beginning of the nineteenth century. At about that time, the explanation was adopted that these successive cataclysms and re-creations were not as sharply marked off as had been formerly supposed, but that on the contrary, the types of one age had blended more or less naturally with those before and after. About the middle of the nineteenth century, this theory was gradually and imperceptibly transformed into the modern theory of evolutionary geology, which is the prevailing view at the present time.

A more detailed study of the rise and progress of the science will be given in a later chapter.

Index Fossils. On a certain occasion, J. W. Powell, director of the United States Geological Survey, was before a Congressional committee, and explained the value of paleontology by saying that it is "the geologist's clock." More recently we have had two large volumes issued by Grabau and Shimer, two prominent paleontologists, the title of these volumes being "North American Index Fossils." Charles Schuchert has a chapter in his "Textbook of Geology," entitled, "Fossils, the Geologist's Time Markers." In various other ways, the position which the fossils occupy in the study of geology has been stated by various writers. Occasionally some dabbler in the science of geology will be found to declare that the rocks of the globe are *not* arranged solely and entirely according to their fossil contents, but that stratigraphic position and lithologic texture are also used, with some other considerations, like base-leveling, disconformaties, and diastrophism, in order to help out the testimony of the fossils concerning the exact age of any definite rock deposit. But such a claim is very misleading. It is like many half truths, which are so often worse than direct falsehoods. It is true that any or all of these considerations are occasionally employed when the fossils are scanty or when their evidence is found to be ambiguous. But no experienced geologist would for a moment admit even the direct contradictory evidence of any or all of these other considerations combined, when confronted with the direct and unequivocal testimony of the fossils. How, then, is it wrong to say that the evidence of the fossils is taken as the one and sole testimony concerning the age of a rock deposit?

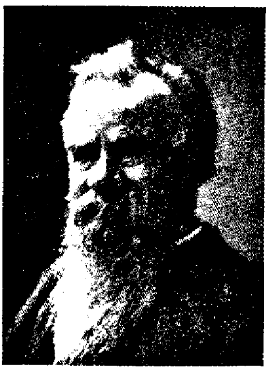

FIG. 178. Major John Wesley Powell (1834-1902).

How Index Fossils Are Used. We may illustrate the way in which the fossils are used to determine the age of a rock deposit. Hundreds of other examples might be given; but these are typical of the rest.

In 1902, the first fossils were brought from the Antarctic Continent. They were only about a dozen all told; but among them were some *fossil ammonites* belonging to genera which had already been found in other parts of the world and had been classified as Cretaceous. It was further known that these particular ammonites were good *index fossils* for certain par-

ticular subdivisions of the Cretaceous, and that these fossils occur in no other formations, either above or below. Accordingly, on the basis of these few fossils, the geological "age" of these rocks in the Antarctic Continent is settled once and for all.

Another example: The rocks of the oil region at Tampico, Mexico, have been hard to classify, as they have yielded few determinable fossils. However, the government printing office, at Washington, D. C., recently issued a paper by Dr. T. W. Stanton describing a new rudistid mollusk belonging to the family *Radiolitidæ*, which is regarded as strictly confined to the

FIG. 179. Sandstone block containing a large fossil palm leaf, from Coryell Coal Mines, New Castle, Colorado. (Gale, U. S. G. S.)

Cretaceous system (Fig. 180). On the basis of this single fossil shell, Dr. Stanton declares that this fortunate discovery "establishes the Cretaceous age of the San Felipe formation in its typical exposures west of Tampico."

In the preceding chapter, we have seen that the great groups of the strata are based entirely on theoretical considerations regarding the order in which the fossils have occurred. The same is true also of the *systems,* which are the subdivisions of next rank. The subordinate divisions, as we have seen, with local geographic names, such as the *John Day beds,* the *Laramie,* the *Niagara,* or the *Dakota formation,* are based largely on field experience; but the place in the geological time-scale to which they are to be assigned is *wholly a matter of fossil evidence.*

If a new set of beds were to be found in Russia, or at Cape Horn, or in Alaska, or in China, and these beds contained *trilobites,* every geologist on earth would assign these beds to some part of the Paleozoic group, the exact position in this group depending entirely upon the *kind* of trilobites. Similarly, if beds containing *belemnites* were found in any of these localities, the rocks would be classed, without any hesitation, as Mesozoic, the position in the Mesozoic group to which they would be assigned depending, as before, upon the *grade* or *char-*

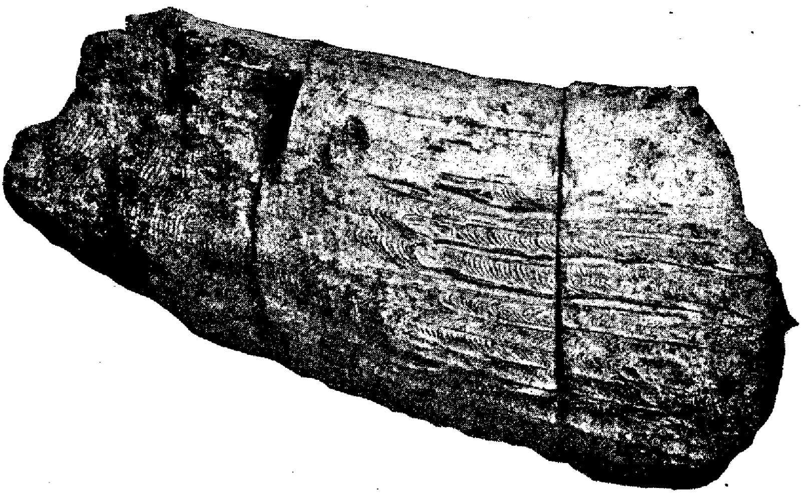

FIG. 180. An "index fossil," *Sauvagesia degolgeri,* Stanton, recently discovered in the Tampico region, Mexico. Dr. T. W. Stanton says of it, that it "establishes the Cretaceous age of the San Felipe formation in its typical exposures west of Tampico." ("A New Cretaceous Rudistid," "Proceedings of the United States National Museum," Vol. 59, p. 453.)

acter of these fossils. So much, then, for the general view of the position occupied by the fossils as the *index* or *ticket* of the exact "age" of a rock deposit.

The consideration of this method, and a discussion of its scientific value, and the logical principles involved, must be left over for another chapter.

Conditions Favoring Fossilization. Plants or animals which are buried wholly under water, as in the deeper waters of the seas, are much more likely to be preserved from complete decomposition than those buried in the soil of the land, because far less oxygen comes in contact with those under the former condition. Both in ancient times and under modern conditions, marine organisms stand a much better chance of being preserved. Indeed, over the lands, there are only insignificant de-

posits here and there which preserve any remains of plants or animals long enough for them to become true fossils.

The following words from Dana state the matter very clearly:

"Over the land, the chance of burial is very small. Plants and all animal matter pass off in gases, when exposed in the atmosphere or in dry earth; and bones and shells become slowly removed in solution, when buried in sands through which waters may percolate. Vertebrate animals, as fishes,

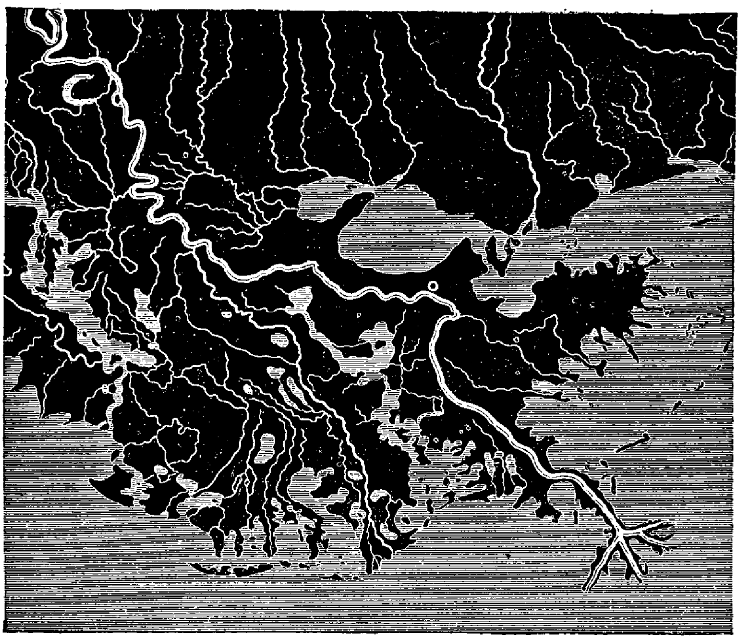

FIG. 181. Delta of the Mississippi.

reptiles, etc., which fall to pieces when the animal portion is removed, require speedy burial after death, to escape destruction from this source as well as from animals that would prey upon them."—*"Manual," p. 141.*

David Starr Jordan declares that "the chances for the preservation of any individual fish are a hundred thousand to one against it."

Insects are rarely found as fossils, while birds are exceedingly rare.

The lowest forms of life are now contributing most toward rock formation, as the corals, crinoids, rhizopods, brachiopods, and mollusks. Since they form hard parts which are largely composed of rock material, the accumulation of these parts contributes very largely to the formation of rocks when the

creatures are dead. On the other hand, the higher forms of life are contributing practically nothing to the mass of rocks in our modern world, a few stray specimens which are buried here and there under very exceptional circumstances being all that are now preserved as fossils.

Usually when any relic of life is buried under such conditions as to insure its preservation as a fossil, there takes place a more or less marked *change in its substance*. The exact form and appearance of the original may be preserved, even while there may be an entire replacement of the original component elements by other very different elements. Such changes are of course chemical processes; and they may result in the replacement of wood or bone by carbonate of lime, by silica, or even by iron oxide, or by pyrite, which is iron sulphide. If we consider wood as a typical example, the mineral matter seems first to fill the cells of the wood, and then it proceeds to replace each particle of the wood, molecule by molecule, as the wood slowly decomposes and passes away; the result being that finally the original material is all gone, and a mass of mineral matter looking wonderfully like the wood is left behind. In common language, the wood has been "turned into stone." As we have seen, this is not wholly an accurate expression, but it is very often used. Sometimes it happens that a fossil log may be carbonized at one end and silicified at the other.

Definition. A fossil may be the well-preserved remains of an ancient animal or plant, or it may be merely the natural impressions made by such an animal or plant upon the surrounding rocks. Even the tracks of birds or reptiles are spoken of as fossil footprints, and the holes bored by worms and found preserved in the older rocks are always spoken of as fossils. The dead bodies of animals are very quickly decomposed and reduced to gases, except such hard parts as may be able for a greater length of time to resist the processes of decay. Plants, likewise, are quickly subject to decay, although various kinds of wood may be preserved, under favorable conditions, for many years or even for centuries. Some of the smaller plants, such as the microscopic single-celled diatoms, have part of their structure composed of silica; and these, with some microscopic animals known as radiolarians, and some of the sponges, often leave behind them these siliceous parts, which are capable of being preserved for many centuries or quite indefinitely. In some of the sponges, the silica occurs in a colloidal form, like opal, which is quite easily destroyed. The diatoms and radiolarians which have been preserved best have the silica in an insoluble

form; and the exact structure of these siliceous spicules can easily be recognized to-day under the microscope, after such long periods of time since they were first deposited.

Calcite and Aragonite. Many types of invertebrate animals, with some few plants, chiefly seaweeds, secrete calcium carbonate as part of their structure. This calcium carbonate is obtained from the waters in which these creatures live. Such a secretion of calcium carbonate may take either of two forms, the one known as *aragonite,* the other as *calcite.* Occasionally an organic structure is found consisting entirely of one or the other of these forms; but more frequently both of these forms of calcium carbonate are found in the same individual. For example, among many shellfish, the inner mother-of-pearl layers are composed of aragonite, while the outer porcelaneous layers are of calcite. In the oysters, however, the calcite usually predominates.

The value of these two kinds of calcium carbonate appears readily upon examination of many fossils; for structures which have been formed of calcite are quite likely to be preserved intact, but those structures composed of aragonite are likely to be dissolved and carried away, or replaced by entirely different minerals which have been brought by the percolating waters. "In the Paleozoic rocks it is almost the rule for the aragonite structures to be gone, this being especially true among the Mollusca, but in the Mesozoic and Cenozoic the mother-of-pearl layers are much more commonly preserved. Just why this is so is not yet determined." (Schuchert.) The skeletons of vertebrates, which are composed chiefly of calcium phosphate, are sometimes found in an excellent state of preservation, as in many peat bogs, or in the asphalt tar pits of La Brea, and other places; but more frequently they are found in a poorly preserved condition.

Other Structures. The skeletons of such animals as insects and crustaceans are composed largely of a nitrogenous substance of quite complicated structure which is known as *chitin.* Most nitrogenous substances are easy to decay, but this material seems to resist the chemical agents of destruction remarkably well. The external skeletons of insects, trilobites, and crustaceans may consist largely of chitin, though lime salts are also occasionally present. The skeletons of such animals have in countless instances been remarkably well preserved, the structure retaining its perfect form for a sufficient length of time to impress its exact mold upon the surrounding rock materials.

The soft parts of animals decay so rapidly that only under exceptional circumstances are they preserved. Yet it is a very common thing to find the entire form of fishes preserved in the calcareous or siliceous sediments in which they were entombed. In such instances, the most minute forms of the creatures are preserved with all the perfection of an intaglio. Such fossil fishes have been found by millions in various parts of the world. Occasionally the muscles and tissues of larger vertebrates which apparently lived on the land, have also been excellently preserved. There is no doubt that in the case of the many fishes

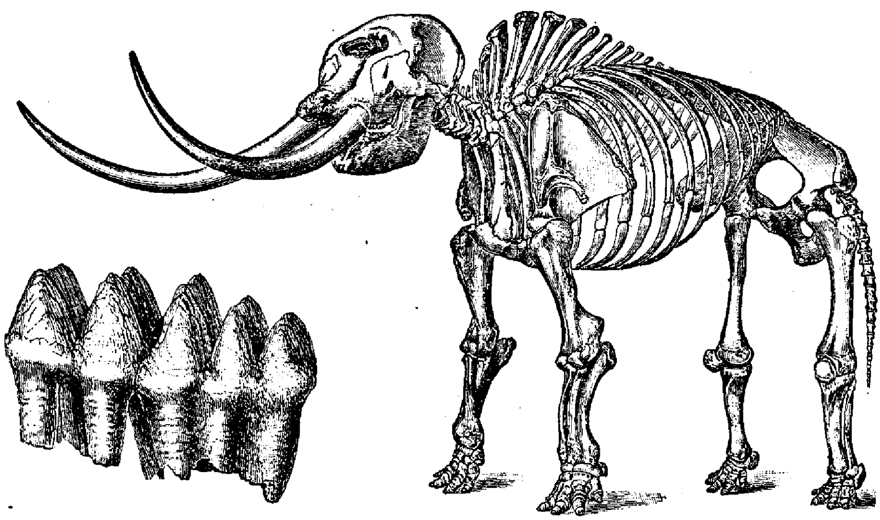

FIG. 182. Restoration of *Mastodon americanus* (× 1/48), by Marsh; tooth of same (× 1/4).

referred to, these creatures were literally buried alive by some sudden influx of smothering sediments which dropped suddenly down upon them from the waters above.

The Siberian "Mummies." The most remarkable cases, however, of the preservation of the soft tissues of animals, have occurred in the tundras of Northern Siberia, the frozen ground in these regions remaining in a solid state for century after century. The remains of elephants, rhinoceroses, oxen, and other animals have been found here in an almost perfect state of preservation. Of these animals, the ancient elephant known as the mammoth, *Elephas primigenius,* is by far the most common, the tusks of the creature in many places protruding from the surface of the half-frozen soil in such numbers that a regular trade in this fossil ivory has been carried on for centuries, some of this ivory finding its way eastward through China, and some

of it westward to Petrograd; and as one author expresses it, fossil ivory has a market quotation of current price just the same as wheat or potatoes. The best-preserved specimens have been found along the banks of such northward-flowing rivers as the Lena, where the current, by undermining a portion of the banks, may occasionally expose a carcass which has been lying in cold storage underground for uncounted centuries. When thus exposed and when the surrounding ice and soil have melted away, the flesh has been greedily devoured by dogs and wolves. Less perfectly preserved specimens have been found also in the frozen soil of Northwestern Alaska.

Other Conditions. The best and most perfectly preserved fossils are found in strata of marine origin which are evenly bedded and which are composed more or less of limestone or magnesian limestone. They are rare in conglomerates, or even in sandstones or in red shales. "In nearly all of the red beds other than red limestones it is the exception to find fossil remains, because the plants and animals have been oxidized and dissipated during the process of subaërial sedimentation. It is therefore the green, blue, gray, black, and subsequently oxidized yellow beds that are apt to hold fossils." (Schuchert.)

It has been estimated that the stratified rocks in general are composed of about 5 per cent limestones, about 15 per cent of sandstones, while shales make up fully 80 per cent. The limestones are usually quite rich in fossils, while the sandstones and shales contain them in varying proportions. The fossils which are found in conglomerates and sandstones are not usually well preserved, and much difficulty has been experienced in gathering together such gigantic specimens of reptiles and other vertebrates as are exhibited in many of our museums, some of these specimens having been found in sandstones so hard that blasting has been resorted to in order to release the fossils.

CHAPTER XVIII

A General View of the Plant and Animal Kingdoms

Living Organisms. Living organisms differ essentially from inorganic or mineral substances.

1. All living beings are composed of *cells* which contain *protoplasm.*

2. They *grow,* not by mere accretion or crystallization, but by imbibing food which they change and use for their self-development.

3. They have the power of *reproducing* themselves. And new living things can come only from preëxisting similar things; that is, no combinations of mere physical and chemical forces can originate life from the not-living.

The great outstanding fact in this connection is that something quite *different from mere physical and chemical forces* is in operation in the living organism. There is evident a power of development, a purposeful growth and adaptation, such as can not be explained by the mere laws of the physical world.

4. Another characteristic just as distinctive of living organisms is what we may term *vital elasticity,* or the ability on the part of the organism to change as an adaptive response to its environment. It is not the environment which produces the change in the organism; *the changes are produced by the organism itself to meet the changed conditions in which it is situated.*

Variation. The investigations of biologists during the last half century or so have given us an increasing appreciation of the amazing extent to which this property of adaptation is possessed by every living form. And the higher and more complex the organization, the greater is its capacity for adaptive response toward its environment. Linnæus founded his term *species* in an attempt to designate precisely "as many forms as were created in the beginning." This naturally led to the idea of the "fixity" of species. Of course, it is true that no amount of selective breeding would ever grow horns on a horse or hoofs on a cat. But we now have facts in abundance at our command which Linnæus did not have, by which we know that species have varied greatly under domestication; and there is every reason to believe that in prehistoric times, even greater

variations may have been produced by nature, though these variations have apparently now become so "fixed" and so distinct by the erection of a barrier of cross-sterility between them that they are now classed as separate "species," or in some cases even as separate genera.

The endeavor to find a scientific explanation of how these variations originate in a natural way, has been one of the principal studies of the last century. Lamarck and Darwin thought that new species were produced by slow, long-continued variations in a gradual way, chiefly by external causes, such as the influence of *the environment* in its broadest sense, together with what may be termed the impersonal factor, "natural selection." Modern scientists, following the lead of Mendel, whose results have been ably supplemented by De Vries, William Bateson, T. H. Morgan, etc., think that new types may have come into existence *suddenly*, though they are now agreed that we do not know the exact process by which "species" really have originated.

But these recent investigations help us to understand somewhat the very remarkable fact that away back in the earliest days of Egypt, the various races of man, such as Negro, Caucasian, Mongolian, etc., are represented precisely as they appear to us to-day, showing that at that very early period, these striking racial differences were already completely established. Evolutionists have been accustomed to argue, from this fact, that before this first dawn of history, there must have been long unnumbered ages during which these differences were gradually accumulating; while the creationist sees in this situation only a confirmation of the record regarding the *compulsory dispersion of the races* soon after the Deluge.

On either view, if we are to study the various races of men as we study mammals, or birds, or fishes, there is no doubt that we should *divide the human race up into many "species,"* perhaps even into several genera. As is well known, even such an accomplished naturalist as Louis Agassiz did this very thing, arguing strongly for the multiple origin of mankind. Among the lower animals, there seems to be a sexual aversion or antipathy that tends to keep these "species" distinct, in cases where geographical barriers do not intervene, even in those instances where, by artificial means, they may be induced to interbreed and produce perfectly fertile progeny. And there is little doubt that if human beings were as true to normal instincts as are most of the lower animals, the lines of demarcation between the various races of mankind would be as clearly marked as between many "species" in nature.

As for the ultimate causes by which these variations have originated, we know practically nothing. Professor William Bateson, in his notable address before the Toronto meeting of the American Association, December 28, 1921, said: "It is impossible for scientists longer to agree with Darwin's theory of the origin of species. No explanation whatever, after forty years, no evidence, has been discovered to verify his genesis of species. . . . We no longer feel as we used to do, that the process of variation, now contemporaneously occurring, is the beginning of a work which needs merely the element of time for its completion; for *even time can not complete that which has not yet begun.*"

From the point of view of a direct creation, we may say that in the origin of these variant forms of animals and plants, as well as in the origin of the various races of mankind, we are witnessing merely another manifestation of the Power behind nature, which undertook to reproduce from the wrecks of plant and animal life left by the Deluge a new world of life only a little less wonderful and beautiful than that which the Creator in the beginning pronounced "very good."

Species. To discuss the probable *limits of species* in a work of this size and character is clearly impossible. It is a very commendable tendency on the part of modern scientists, that a strong reaction has set in against the mania which prevailed during the nineteenth century, for multiplying new specific names. This reaction is especially noticeable in works dealing with the mammals, where a knowledge of the fact that numerous "species" are perfectly cross fertile has often led modern systematists to group perhaps ten or twenty of them together under one name. Among the lower forms of life, and *especially among those very forms that are of the most importance in geology,* such as mollusks, brachiopods, crinoids, corals, etc., we are still pitifully ignorant of their life-history from the ovum to maturity, many of them living miles down in the ocean, or under other conditions which render it quite impossible to conduct control experiments. Thus among these lower forms of life, there may still be many modern kinds which are merely the modified descendants of kinds found as fossils in the rocks, though slightly different in one or more important characteristics. However, on the whole, it would seem to be wise for the present to follow the current classification of species and genera, but with this mental reservation, that most of the "species" under any given *genus,* whether plant or animal, are probably artificial distinctions, the various modern forms having probably all descended from one stock. In some instances, *perhaps*

even the different genera of a family may be thus of a common origin.

But in all this, it is very important to bear in mind that this *is by no means to concede the doctrine of evolution.* The real creationist can afford to be liberal in respect to species, for he knows that a correct view of geology forever puts the evolution theory out of possible consideration. We may thus account for

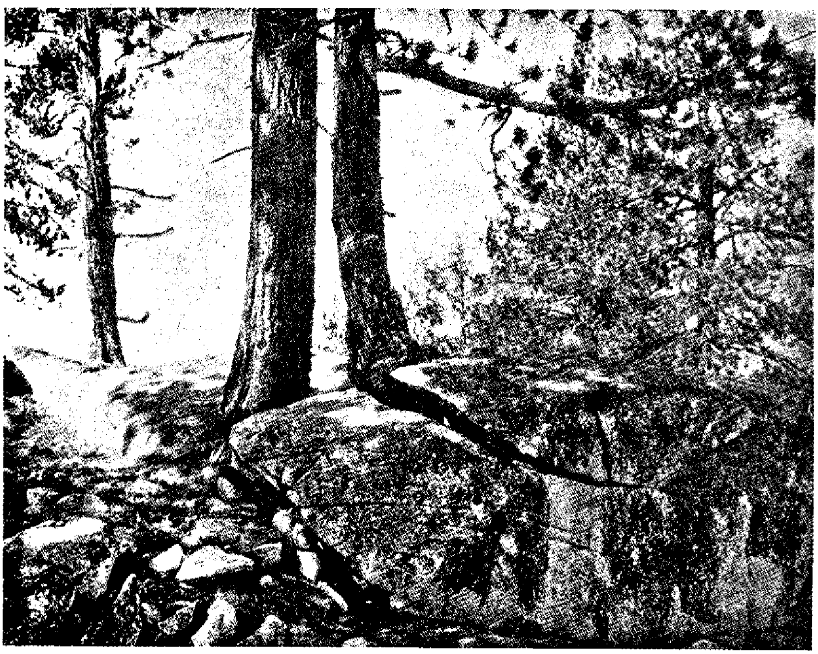

FIG. 183. Rock split by the growth of a tree, Sierra Nevada, California. (Gilbert, U. S. G. S.)

many "species" and even for some "genera," but such an explanation of the origin of variations *does not touch the problem of accounting for the originals out of which these are derived.* It merely helps the believer in the Bible, by showing him how all the modern world could easily have grown out of the ruins of the world surviving from the great world catastrophe; but back of all this, of course, *there must have been a direct or literal creation of the originals from which the modern forms and the fossils were alike descended.*

Distinctions Between Animals and Plants. The system of life as a whole is divided into two kingdoms, the animal and the

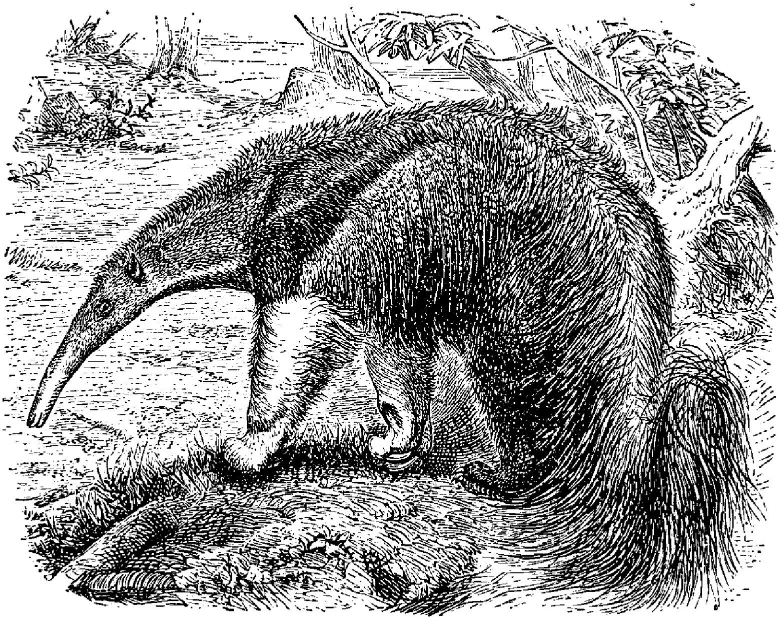

FIG. 184. The great anteater (*Myrmecophaga jubata*). (From Sclater, *List of Animals in Zoölogical Society's Gardens*, 1883, p. 190.)

vegetable, which are mutually dependent upon each other. The following are some of their characteristics:

1. All animals, save the very lowest, have a *mouth*, and receive food into it or into a *stomach*. Even most of the lower forms of life extemporize a mouth and a stomach for the apprehension of food, so that even in these cases, the food is digested in an interior cavity. On the other hand, plants take their nourishment entirely *by absorption*.

2. Plants absorb carbon dioxide, keeping the carbon and setting free the oxygen; animals inhale oxygen, which in their bodies unites with carbon, forming carbon dioxide, which is then thrown out by the animals and ultimately furnishes food for the plants.

3. Plants take inorganic matter as food. But animals can not thus feed upon the inorganic; this must be prepared for them by the plants as intermediaries.

This is the one invariable test to distinguish plants from animals among those lowly forms where all other tests fail. It is interesting to note how the Bible millenniums ago recognized the plant as the necessary instrument in preparing food for the animal. (Psalm 104: 14.) Food for animals can be brought

forth "out of the earth," or from the inorganic, only by passing through the intermediate stage of plant life.

4. No plant possesses *self-consciousness,* nor does it possess consciousness of other external existences. Contrastedly, all animals seem to be conscious of an external world, even the lowest forms showing this consciousness by avoiding obstacles.

Some biologists have thought that they could distinguish a difference in chemical composition between the protoplasm of plants and that of animals. Others emphatically declare that no such difference exists. But quite evidently the more nearly alike are the cells or protoplasmic units of these widely different forms, the more clear does it become that only some directing Power behind all the cells of these multiform kinds of life guides each in its own particular method of development, and on a plane distinctly above that of dead, inorganic matter. Certain it is that life in all its forms is a manifestation of divine Power that can never be interpreted in terms of physics and chemistry.

The Animal Kingdom

All animals may be divided into two groups: I. *Vertebrates;* II. *Invertebrates.*

The first of these possess a backbone, or vertebral column, and along the dorsal side of this column, a bone-sheathed cavity which holds the spinal cord or the great central nerve. A cross section of a vertebrate's body shows two cavities: the *dorsal,* containing the cerebrospinal nervous system; and the *ventral,* containing the digestive, circulatory, and respiratory systems.

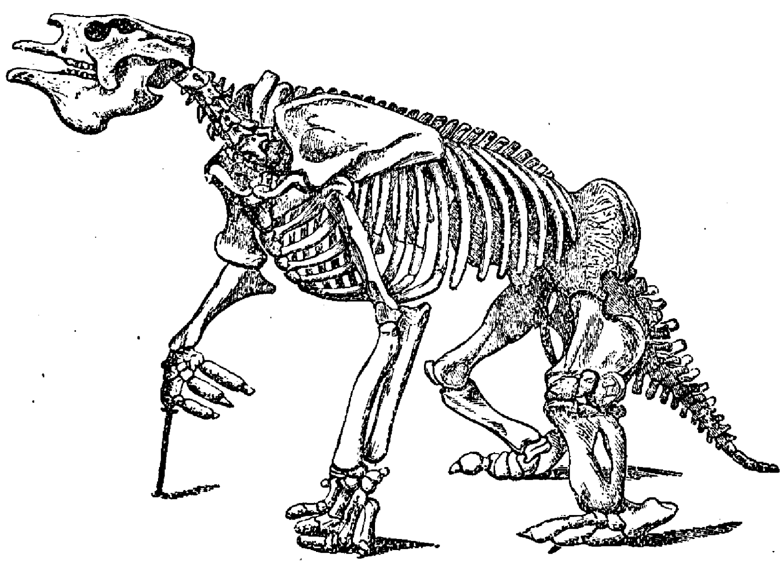

FIG. 185. Skeleton of *Megatherium,* from the specimen in the Museum of the Royal College of Surgeons. × 1/25. (After Flower and Lydekker.)

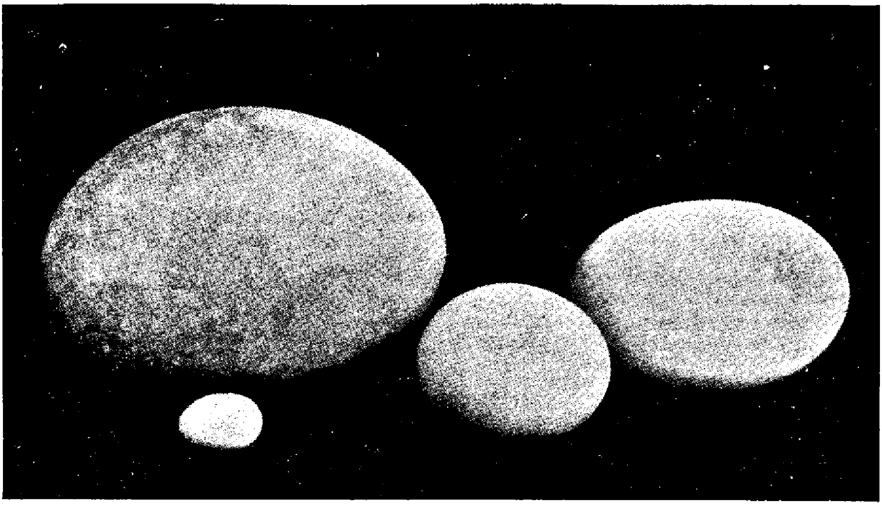

FIG. 186. Eggs of feathered giants, Epiornis, ostrich, moa, compared with a hen's egg.

The invertebrates have these two cavities reversed; that is, the chief nervous cord is below, or ventral in position, instead of above. All vertebrates have a liver, and usually have a well-developed nervous system.

The vertebrates include mammals, birds, reptiles, amphibians, fishes.

The more important characteristics of these five classes of vertebrates must now be given.

1. Mammals

Mammals nourish their young by milk; breathe air by means of lungs; and have a heart of four cavities. There are three subdivisions:

a. The *viviparous*, or placentals, which bring forth their young alive; as man, all the ordinary quadrupeds, and also bats, whales, and seals.

b. The *semioviparous*, the young of which are quite immature at birth, and are transferred to a maternal pouch, where they are suckled until maturity; as the kangaroos of Australia, and the little opossum of America. These are also called *marsupials*.

c. The *oviparous*, or monotremes, which lay true eggs, from which the young are hatched, as the duckbill and the echidna of Australia.

2. Birds

These are oviparous, or reproduce themselves by true eggs; breathe air by lungs; have a heart of four cavities; are warm-blooded; are covered with feathers; and usually have wings for

flying. Existing birds do not have teeth; but some fossil birds from the Mesozoic rocks had a full set of teeth; some of them had long vertebrated tails.

3. Reptiles

Generally oviparous; breathing by lungs; having a heart of four or three cavities; covered with scales or naked. They include snakes, turtles, tortoises, lizards, crocodiles, and alligators. Most of the living reptiles are not very large; but many of those found as fossils were among the very largest of land animals, being more of the order of whales, so far as size is concerned.

4. Amphibians

Mainly oviparous; when young breathing by gills, afterwards by both gills and lungs or by lungs alone. The heart has three cavities. Toads and frogs lose their tails as well as their gills when mature. Some ancient kinds of amphibians, found as fossils in the Permian and other formations, had scales like reptiles, with strong teeth; while all the kinds surviving into our modern world are naked and chiefly toothless.

5. Fishes

Being of much more importance in geology than any other vertebrates, fishes will demand a more careful consideration.

They are mostly oviparous; have a heart usually of two cavities; breathe by gills; and have the skin naked, or covered with scales, or with bony plates.

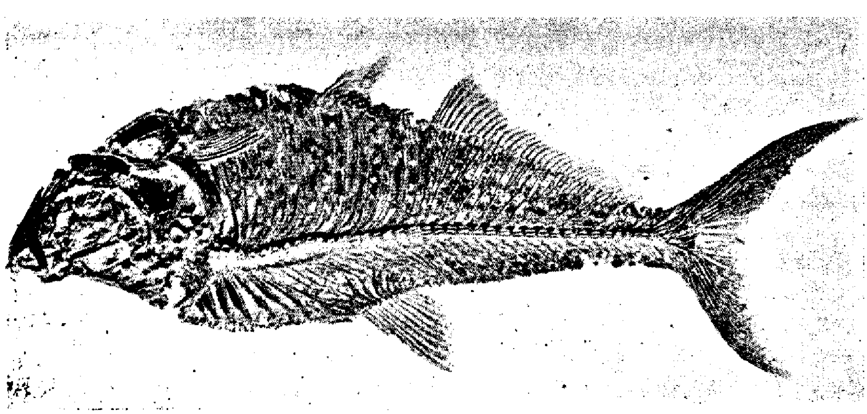

FIG. 187. Diplomystus, an ancient member of the shad family. From the fish bed at Green River, Wyoming. (From a specimen in the United States National Museum.)

Without attempting any formal classification of this class, we may note the following subdivisions:

Teleosts. Nearly all the existing fishes, except sharks, rays, and a few others of low order, are grouped under this name. As is implied in the name, they have a true bony skeleton. The gills are free, and the body is usually covered with scales. Out of a total of about 13,000 species of fishes that have been described, probably over 11,000 are of this order.

Selachians, Gars, and Dipnoans. The selachians include the sharks and the dogfishes. The rays are closely related forms. They have a cartilaginous skeleton; have generally several gill

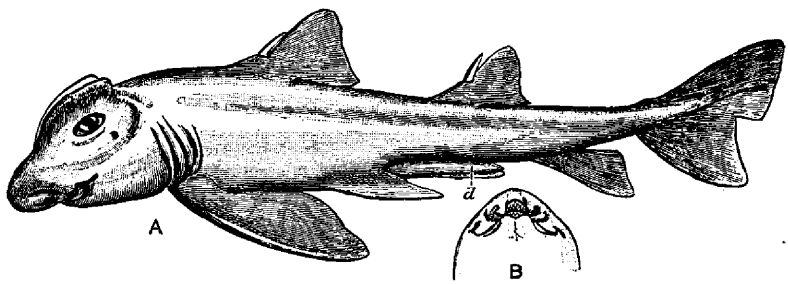

FIG. 188. Port Jackson shark (*Heterodontus philippi*). *A*, lateral view; *B*, mouth and nostrils. (From a specimen in the Cambridge University Museum, after T. W. Bridge.)

openings with no gill cover; no air bladder; and usually not proper scales, but a rough skin called *shagreen.* The common sharks have the mouth underneath and separate from the nostrils, with sharp-edged teeth. But the *bullhead* sharks — one genus (*Heterodontus* = *Cestracion,* Fig. 188) with four species constituting all that are now alive, while many are found fossil — have a bony pavement in the mouth in addition to a row of teeth. Many ancient sharks, like some modern ones, had large spines connected with the fins, which, with some teeth and pieces of shagreen, are almost all the remains of these fishes which are found as fossils. Some of the best-known modern sharks are viviparous.

Under the term *ganoids,* Agassiz included forms that have since been separated into various groups, only some three orders being still alive, including the *Polypterus,* the sturgeon, and the gar pike (*Lepidosteus*). But the fossil forms are very numerous in the Paleozoic and Mesozoic rocks. Modern forms have a more or less ossified skeleton, while many of the ancient types had a cartilaginous one. The skin is covered with thick bony scales, or even bony plates which somewhat resemble the cover-

ing on a turtle or the armor of a battleship. While probably modern forms can not be proved to be identical with any particular kinds found in the Devonian rocks, the popular chronological arrangement of these fishes shows the folly of the popular theories, since this arrangement makes these surviving forms appear to skip many whole geological ages, or from the period where they occur down until the modern.

The *dipnoans,* or lungfishes, have both gills and lungs, and can live by breathing air. The Ceratodus of Australia has skipped from the Mesozoic to the modern, while the Protopterus of Africa and the Lepidosiren of South America do not appear to have been found at all in the fossil forms. Great numbers of fossil dipnoans are found in the Devonian, Carboniferous, Triassic, and Jurassic rocks.

A still further group of fishes, called the *Cyclostomas,* is usually made by the zoölogists, to include the hogfishes and the lampreys. They are not geologically important.

Invertebrates

The distinction between vertebrates and invertebrates does not suit some modern zoölogists very well, as various forms have been discovered which seem to be both or neither. The *tunicates,* or *ascidians,* also called sea squirts, are commonly placed with the invertebrates. In the mature state, they are fastened to the bottom of the ocean like a plant and have lost all their organs of locomotion, and to an outside view, they look like a bag with two holes, through one of which the water enters, and passes out through the other. In the larval stage, however, the animal swims around in a sort of tadpole fashion, having many points of resemblance to the young amphibians. Hence these curious creatures have been said to be "degenerate vertebrates"; for in modern biology, it has become the fashion to measure everything according to its embryonic development. Tunicates are not found as fossils.

The *lancelet,* or Amphioxus, is another form which is usually classed as a vertebrate. It looks a good deal like a worm; but unlike the latter, it has gill slits, a notochord above the intestine, and a spinal cord dorsal to the notochord. It is not found fossil.

The classification of invertebrates is a difficult and unsatisfactory task, no two authors agreeing in all details. In the following outline, we have in a measure followed the results of modern classification as seen in such works as the "Cambridge Natural History" (10 volumes); but wherein we have deviated from it in the order of the groups, in names, or otherwise, we

have done so largely in favor of the methods still retained in most geological textbooks, for the latter are conservative in the matter of adopting new names for the orders and classes.

Articulates	I. Arthropods a. Terrestrial species 1. Insects; 2. Myriapods; 3. Arachnids b. Aquatic species 4. Limuloids; 5. Crustaceans	
	II. Worms	
Non-Articulates	III. Mollusks	
	IV. Brachiopods	
Radiates	V. Echinoderms	
	VI. Cœlenterates	Hydrozoans Actinozoans (Polyps)
	VII. Sponges	
	VIII. Protozoans	Rhizopods Radiolarians

I. Arthropods

The terrestrial species of the Arthropoda have spiracles (breathing holes), a vascular system for the circulation of oxygen inside the body, but with no antennæ, or but a single pair. They include the insects, myriapods, and the arachnids.

The aquatic species have gills with which to absorb oxygen from the water, or sometimes this function is carried on through the general surfaces of the body. The aquatic species include the limuloids and the crustaceans. Some 200,000 modern species of arthropods have been described, while only about 5,000 have been found fossil.

(1) Insects

These have a distinct head, thorax, and abdomen. Some of the various groups are: hymenopters (ants, bees, wasps); lepidopters (butterflies, moths); coleopters (beetles); dipters (flies); neuropters (dragon flies, May flies).

(2) Myriapods

These have a regularly articulate body, wormlike in form, with numerous pairs of legs; as the centipedes and the millepedes. They are very rare as fossils.

(3) Arachnids

These have a body in two parts, and include the spiders and the scorpions. They are not very common as fossils.

(4) Limuloids

The only species of this group found living in America is the horseshoe crab, or king crab (*Limulus polyphemus*), found on the Atlantic coast. These creatures differ considerably from the crustaceans, being somewhat like the arachnids; but they are chiefly interesting as being the scanty remains of almost identical forms found in large numbers in the Paleozoic rocks. Some of the ancient limuloids, known as eurypterids, were several feet in length.

(5) Crustaceans

These are subdivided into (1) decapods, as crabs, lobsters, and shrimps, having ten feet or five pairs of appendages; (2)

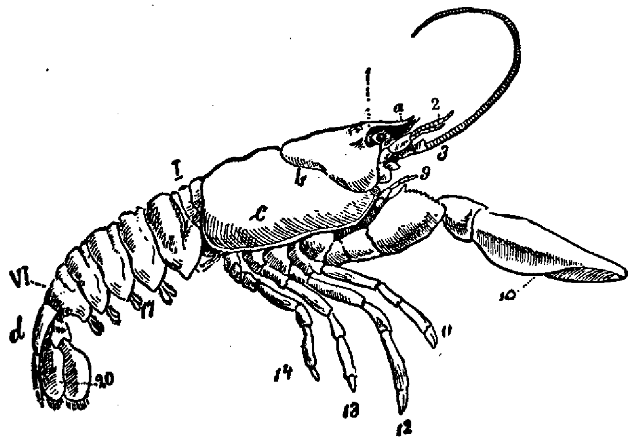

FIG. 189. The crayfish. Adult male. *a*, rostrum; *b*, cephalothoracic shield; *c*, gill; *d*, anal segment; I-VI, abdominal segments; 1, eye stalk; 2, 3, feelers; 9, outermost jaw-foot (maxilliped); 10, chelate foot; 11-14, walking feet; 17, swimming feet (pleopoda); 20, caudal fin. (After Huxley.)

tetradecapods, having fourteen feet, as the sow bugs and sand fleas; with many extinct species, the most important of which are the trilobites; (3) cirripeds, or barnacles.

As already remarked, by far the most important of these groups, from the point of view of geology, are the *trilobites*. As shown by Beecher and Matthew, they had not only slender legs, used perhaps as organs for swimming, but delicate antennæ, like some of the modern sow bugs and sand fleas, to which they were related in structure. But they were usually much larger than any of the latter, many of them being several inches in length. They have been divided and subdivided into a tiresome number of genera and species, each separate kind being used as the infallible ticket of a distinct "age" or "era" of the earth's early history, in the fanciful scheme of the evolutionary geologists.

II. Worms

Several kinds of worms (*Vermes*) are found as fossils, but they are not of much geological importance. In the evolutionary scheme, they are used as the precursors of the crustaceans and the other arthropods.

III. Mollusks

There are about 45,000 species of living mollusks already described, and the end is not yet. Mollusks have soft, fleshy bodies without joints or appendages of any kind. They include the oysters, clams, snails, limpets, pearly nautilus, and the cuttlefishes. The modern slugs belong here; but as they have no shells, they are not found as fossils. The chief subdivisions are:

1. *Cephalopods.* These are free-swimming species, having four or five or more pairs of arms arranged about the mouth, as the nautili and the ammonites (Fig. 191), which have an external chambered shell, and the devilfishes, cuttlefishes, and squids, which have no external shell. One species of squid found in the seas off Newfoundland has a body 15 feet long, and arms 35 feet. The pearly nautilus is the sole survivor of very numerous forms found in the Paleozoic rocks.

2. *Gastropods.* These include the chitons, snails, and slugs. Some small free-swimming forms called *pteropods* are still found in great numbers in the open waters of the ocean, and much larger kinds are found as fossils, their remains giving rise to the phosphate beds of the Southern States and elsewhere.

3. *Pelecypods.* These include the clams, oysters, and other true bivalves. The two valves cover the right and left sides of the body, and are held together by one, two, rarely more, adductor muscles, which leave the impressions of their attachments on the interior surfaces of the valves near the hinge. The prominence on a valve near the hinge is called the *umbo* (plural, *umbones* or *umbos*), or beak.

Some species of pelecypods burrow in the mud at the bottom of the water, and these forms usually gape widely when the animal dies, this opening of the shell being brought about by the strong elastic ligament which unites the two valves. When any of these species are found as fossils with the valves applied and hollow — that is, without any mud or sand having been washed into the shell cavity — we have proof that the animals must have been buried alive, or at least buried before decomposition of the soft parts took place. Mollusks are very common as fossils, some 21,000 species having been described.

IV. Brachiopods

These were formerly called *molluscoids,* since they have a bivalve shell like the pelecypods. But the valves, instead of being lateral, are dorsal and ventral; that is, they cover the top and the bottom of the creature. The two valves are unequal in size, but each is symmetrical in form. They do not tend to spread open when the animal dies. Through a hole in the upper valves near the beak, there passes a *pedicel,* or *stalk,* forming a part of the body of the animal, by which it fastens itself to the bottom of the ocean or to some fixed object. When the animal dies and this stalk decays, there is left a hole in the shell which will admit mud or sand if the shell is exposed to currents of moving water. Accordingly, when brachiopods are found as fossils with the valves applied and the *interior hollow,* it would seem to indicate that they must have been buried before decomposition took place. The fossil forms probably lived in the deeper parts of the ocean, where there is naturally no action of marine currents and no formation of true stratified deposits.

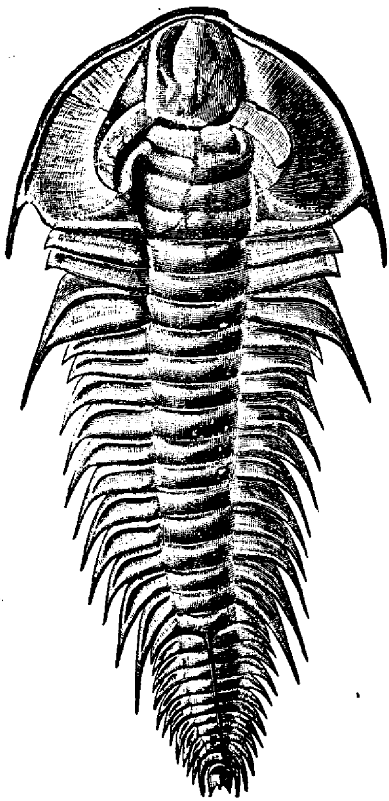

FIG. 190. A Lower Cambrian trilobite, formerly called *Olenellus vermontanus,* but now called *Mesonacis vermontana* Walc.

Certain living species, as for example *Terebratula vitrea,* seem to be found over practically all parts of the ocean, and at almost all depths, specimens having been dredged from over 1,400 fathoms. *Terebratula Wyvillei* has been recorded from 1,035 to 2,900 fathoms, and *Discinisca atlantica* from 690 to 2,425 fathoms, while *Atretia gnomon* has been found at from 650 to 1,750 fathoms. Even those forms which are often found in shallow water generally extend their range also down to depths much below 100 fathoms.

There are only about 160 species of living brachiopods, and they are usually very localized; that is, they live in but few localities in widely scattered parts of the ocean. But when they

are found, they are commonly in large numbers. As fossils, they are among the most important of all the kinds found in the rocks; at least, in the Paleozoic rocks, they appear to outnumber all the other fossils put together, constituting some 7,000 species. However, only about 20 species have been found in the Cenozoic rocks of North America.

Little was known of the anatomy of the brachiopods until about the middle of the nineteenth century, and almost nothing was understood of their embryology until 1861. Even now very

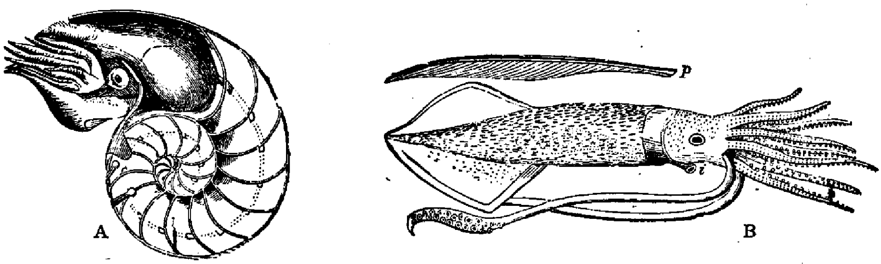

FIG. 191. Modern cephalopods. *A*, the pearly nautilus; *B*, the squid (*Loligo vulgaris*), with a body 6 to 12 inches long; *i*, the funnel through which the ink and water are thrown out; *p*, the "pen." The giant squid is many times larger than this.

little is known of their embryonic development or of the habits of the larval forms. The ova seem to develop in brood pouches of the mother, and after hatching into a free larval form, the young creature swims around and looks for a location. When this is found, it settles down, attaches itself, and never after leaves this spot. "The extreme minuteness of the larva and the short time it spends in this motile condition, probably accounts for the fact that brachiopods are extremely localized." ("Cambridge Natural History," Vol. 3, p. 481.)

Among the kinds of brachiopods that have continued with little change to the present day, are *Lingula* from the Cambrian, *Discina* and *Crania* from the Cambro-Silurian, with *Terebratula* from the Devonian. *Rhynchonella* also is found in Cambrian and Silurian rocks.

V. Echinoderms

These include the sea slugs, sea urchins, starfishes, and crinoids, or stone lilies. All but the last of these lend themselves so well to experimental work that they have become favorite specimens for use in the laboratory; yet, in spite of this, they are not well known as to their embryonic growth or proper classification. Perhaps the chief reason for this is that they show so much *individual variation* that it is almost impos-

sible to classify them. They also show very great capacity for *hybridism;* and consequently we may conclude that they may possibly have sprung from very few original forms. There are about 2,500 living and 2,600 fossil species.

Crinoids are very important as fossils, and their remains have furnished materials for many of our largest deposits of limestone. Over 500 species of crinoids are still living, and are usually found at great depths. Because of this latter fact, their life-history is not well known, and the limits of their possible variations are absolutely unknown.

VI. Cœlenterates

These include the jellyfishes, and the coral polyps, the remains of some of which are very common as fossils. They begin life as ciliated free-swimming larvæ; but in a few hours or days, they attach themselves to some rock or shell at the bottom and start the process of budding, thus forming colonies in the case of those that are colonial in habit. In this class, as in so many others, much confusion has been brought into the study

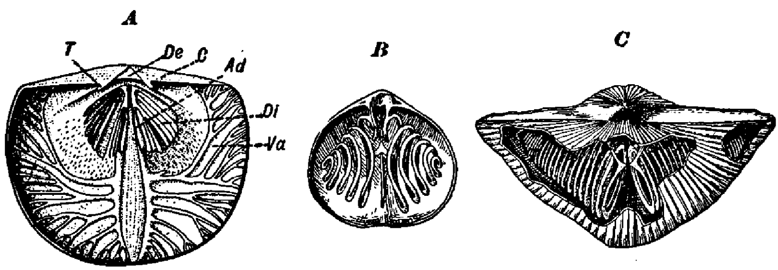

FIG. 192. Internal character of brachiopods. *A*, ventral valve of a strophomenid (*Rafinesquina expansa*). *B*, dorsal valve of a spire bearer (*Nucleospira*), showing the skeleton that supports the arms. *C*, both valves with the dorsal shell broken to show the spiralia (*Spirifer striatus*). *Ad*, adductor scars; *C*, cardinal area, which also makes the hinge of the valves, and to which are attached the teeth (*T*); *De*, open delthyrium where the pedicel emerged; *Di*, diductor muscle scars; *Va*, vascular markings. (After Schuchert and Davidson.)

of the subject by the pernicious custom of assigning *new names* for the forms found as fossils, even different generic or family names, merely to avoid the awkward acknowledgment that the fossils of the so-called "oldest" strata *still have living representatives in our modern ocean.* This custom is the outgrowth of the early days of natural science, when the fossil kinds alone were known; because, strange as it may seem, in almost all the great divisions of the animal kingdom, the *knowledge of the fossil forms long preceded that of the living.* But it is much to be deplored that these artificial and confusing distinctions are still

perpetuated. As an example from this group, we have the *Syringopora*, which is so common in the Carboniferous and other limestones. It resembles some of the reef builders of the East Indies so closely that it can be separated only with difficulty, while our complete ignorance of the possibilities of variation among these forms makes all our conclusions regarding distinctions between them of very little value. Some 3,000 living species of Cœlenterates are named, with about 1,780 fossil species.

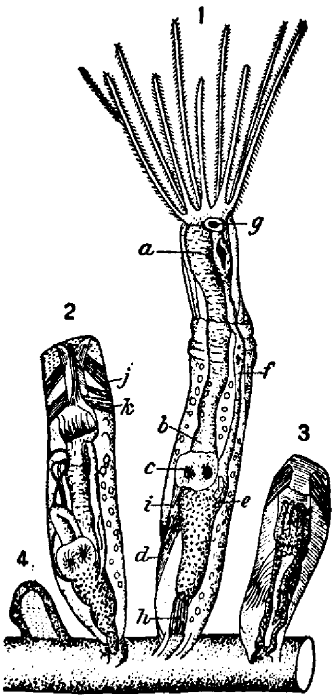

FIG. 193. A typical polyzoan (bryozoan). 1, animal of *Bowerbankia densa*, fully expanded: *a*, pharynx; *b*, cardia; *c*, gizzard; *d*, stomach; *e*, pylorus; *f*, intestine; *g*, anus; *h*, muscles. 2, the same animal when completely retracted: *j*, *k*, opercular retractor muscles. 3, an immature animal. 4, a bud in its earliest state.

VII. Sponges

"No group among the invertebrates," says Zittel, "resisted scientific treatment so long as the fossil sponges." In fact, it was not until the time of the *Challenger* expedition, or about 1876, that the various fossil genera found in the English chalk were proved to be identical with the living sponges. The living species number only about 600, while some 800 are found as fossils. Those that form siliceous or calcareous fibers or spicules are of geological importance.

VIII. Protozoans

These creatures illustrate the principle that the most insignificant beings can often accomplish the very greatest results. The protozoans are all minute or almost microscopic creatures; yet, through their profuse abundance, they have produced enormous quantities of rock. Some 4,400 living species are named, with less than half as many fossil ones.

Two groups only, the Foraminifera and the Radiolaria, are of any geological importance; and hence these are all that call for mention here.

"A very remarkable point which has led to great confusion in the study of the *Foraminifera*, is the fact that the shell on which we base our characters of classification, may vary very much even within the same individual." ("Cambridge Natural

History," Vol. 1, p. 66.) Many of their shells so closely resemble the nautilus that they were first described as minute cephalopods or cuttlefish by d'Orbigny.

The *nummulites* are now classed with the Foraminifera, but are somewhat larger than the Globigerinæ. Their remains make up the enormous masses of nummulitic limestones which are so abundant in the Alps, the Himalayas, and other mountain ranges of the Old World, the pyramids of Egypt being largely built of nummulitic limestones.

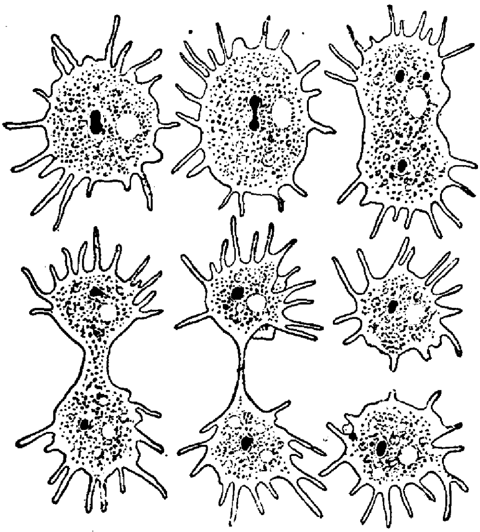

FIG. 194. Amœba. Beginning at the upper left-hand figure, the successive drawings show the progress of a division of an amœba through its nucleus into two. (From "The New International Encyclopædia," by permission.)

Radiolarians. These also are minute creatures, and secrete siliceous shells symmetrically radiate or circular. The radiolarian ooze occupies some 4,000,000 square miles of the bottom of the Pacific Ocean, from two to four miles deep. Fossil radiolarians seem to be found in almost all the various formations; but we can not depend very much upon the distinctions which are often made between the species. As Hartog remarks, "Possibly many of the species may be mere states of growth, for it is impossible to study the life-histories of this group." ("Cambridge Natural History," Vol. 1, p. 87.)

Diatoms are the siliceous shells formed by minute plants. They live near the surface in both salt water and fresh, and their spicules or shells fall to the bottom and form thick chalklike deposits, which are often made use of as polishing powders.

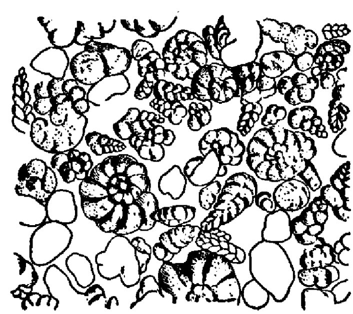

FIG. 195. Chalk from Kansas, × 45. (After the Geological Survey of Iowa.)

The Plant Kingdom

The remains of plants are of vast geological importance. They not only have produced some of the most ex-

tensive coal deposits, but also have left their abundant traces in rock strata in the arctic regions and in other places, where they tell us a very clear and unambiguous story of the climate and other conditions amid which they lived. However, it will not be necessary to give a detailed account of all those kinds of plants which are found as fossils. A few of the more outstanding plant forms which occur as fossils will suffice at this time. A more detailed account of some of the plants producing the Carboniferous coals will be found in the chapter dealing with the formation of these deposits.

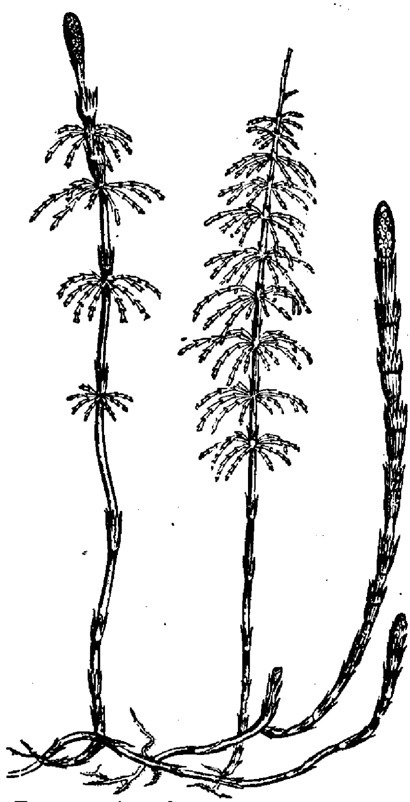

FIG. 196. A modern horsetail, or scouring rush (*Equisetum arvense*), which grows in wet places in almost all parts of the world.

Algæ, fungi, and *lichens* constitute three groups of what are termed *thallus* plants, because they form a simple structure, called a thallus, which is not definitely separated into root, stem, and leaf, though possessing parts which resemble these organs of the higher plants.

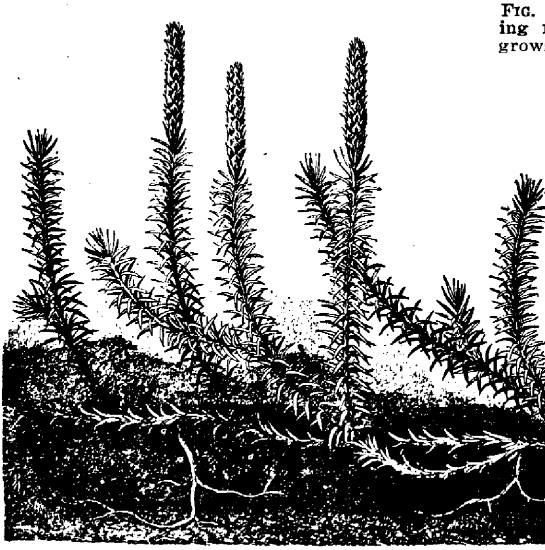

FIG. 197. A modern ground pine, or lycopod (*Lycopodium annotinum*). The stem arises from a creeping rootstock.

Some of the algæ have formed and are even now forming vast deposits of lime, being associated in this work with the corals of the tropical seas. They are known collectively as *nullipores.* The *diatoms*

are minute algæ which secrete silica. The green, brown, and red algæ comprise most of the common forms known collectively as seaweeds. They are not of any great geological importance, though some of them have been recognized in the fossil form. The fungi and the lichens are not of much geological importance.

The mosses and the liverworts are included under the term *bryophytes*. One of the mosses (*Sphagnum*) grows practically from the water, and in places helps to form large peat deposits.

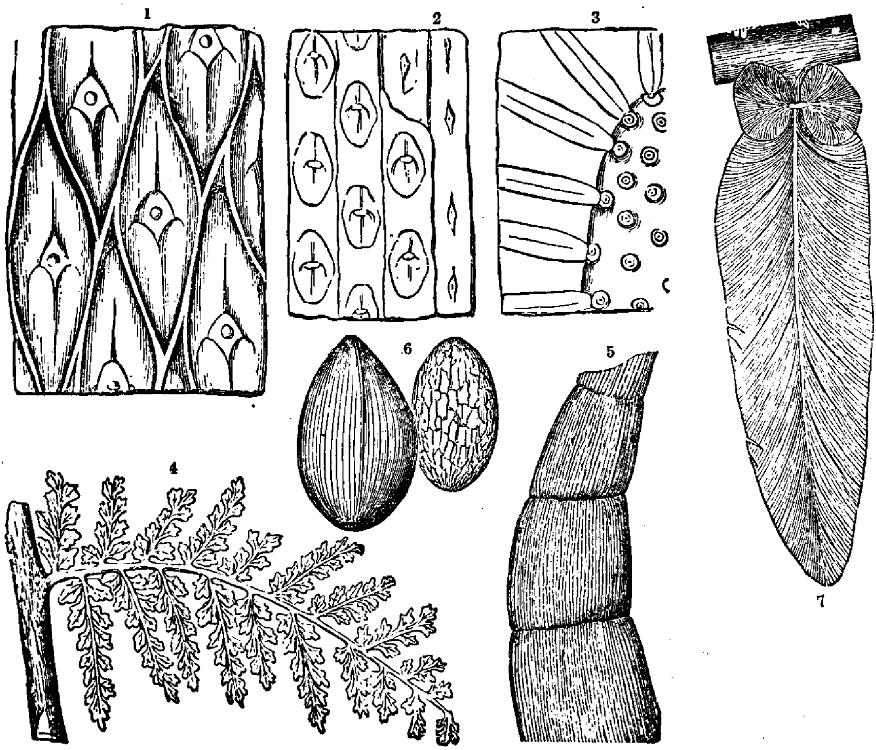

FIG. 198. Permo-Carboniferous plants. 1, *Lepidodendron obovatum;* 2, *Sigillaria oculata;* 3, *Stigmaria ficoides;* 4, *Sphenopteris gravenhorstii;* 5, *Calamites cannæformis;* 6, *Trigonocarpum tricuspidatum.* 4 and 7 are regarded as Permian. (After Dana.)

Traces of fossil mosses have been detected; but the mosses are not of geological importance.

The *pteridophytes* are a very important group of plants, and include the equiseta, the lycopods, and the ferns proper.

The modern equiseta, or horsetails (*Equisetum*, Fig. 196), are small spore-bearing plants growing in wet places in many widely scattered parts of the world. The ancient types include the giant *calamites*, which were veritable trees, sometimes nearly 200 feet high.

The *lycopods* are familiar to us as the club mosses (Fig. 197), their prostrate rootstocks and graceful leafy stems being often used in the East and the North for Christmas decorations. The ancient kinds were often 100 feet high, and comprise the very important *Lepidodendrons* and the *Sigillaria*, which will

FIG. 199. *Cycas revoluta*, in New York Botanical Garden. Cycads closely resemble certain kinds of palms in appearance; but the cycads are gymnosperms, resembling the conifers in the structure of the wood and in the simple structure of their flowers; thus they are extremely different from the palms. (From "The New International Encyclopædia," by permission.)

be more fully described in the chapter dealing with the subject of the formation of coal.

True ferns (Fig. 198), which reproduce by spores, are found as fossils in some of the Paleozoic rocks; but along with them are other fernlike plants which are termed cycad ferns (*Cycadofilices*), and which were not only treelike in point of size, but which also produced parts which were equivalent to true seeds. The modern sago palm belongs to this group, while the maidenhair tree, or Ginkgo, is a closely related form. The latter has broad, fanlike, undivided leaves, and while abundant in many of the Mesozoic rocks, is still living, and widely grown for

ornamental purposes, having been imported from China and Japan.

Spermatophytes. Among the true conifers, the sequoias are very common as fossils, and are represented by the two modern California species, *Sequoia gigantea* (Fig. 200) and *Sequoia sempervirens,* the latter being more familiarly known as the redwood. Their fossils occur in Greenland, Dakota, Switzerland, and many other interesting places. The pines, spruces, firs, and larches comprise some of our most important trees, most of the modern kinds having been found as fossils.

FIG. 200. *Sequoia gigantea,* among firs, Giant Forest, Kaweah Basin, California. (Gilbert, U. S. G. S.)

The *angiosperms* comprise the true flowering plants, and include our fruit trees, as well as such familiar objects as our deciduous forest trees, such as the oaks, elms, birches, beeches, maples, walnuts, with hundreds of others, most of which have been found preserved as fossils in the rocks of the long ago.

CHAPTER XIX

The Pre-Cambrian Rocks

The Basement Complex. It seems to be the fate of speculative geology that it begins its work in the dark; for the *beginning of the geological series* is by all odds the most complicated of the whole. Usually we can not see very distinctly in the dark; and a similar handicap awaits the student of geology who undertakes to trace out a definite starting point from which to begin a geological history.

FIG. 201. Sir William Logan (1798-1875), pioneer of Canadian geology.

Of course, geologists did not begin at the beginning; for in the early days of the science, the workers started with the rocks nearest at hand and those most easily examined, which in England, where much of the first work was done, happened to be chiefly the Jurassic and Cretaceous rocks. After these had been examined and classified, the early workers began to go back farther and farther into the mass of complex rocks found underlying these stratified beds in England, Wales, and Scotland. The tacit assumption that what they found in these localities were of *universal* extent, applicable to the entire world, was carried with them as Sedgwick and Murchison gradually extended their studies down into the earth; and on this basis, the systems now known as Cambrian and Silurian were gradually worked out and brought into something like their modern form.

However, the lowest of these beds seemed to rest everywhere on a *world-wide unconformity;* while below this was a vast series of gneisses and other crystalline rocks which were then known as the *Primary* rocks.

In America, William Logan (1798-1875), the first director of the Geological Survey of Canada (Fig. 201), was one of the pioneers in studying and classifying these most ancient of the

rocks appearing at the surface of the earth, which are still often referred to as the *"basement complex,"* the two words telling the whole story of their characters. Practically all of Canada north of the Great Lakes and east of Lake Winnipeg and the Mackenzie River, is composed of these primitive rocks, variously called *Archæan, Primitive,* or *Pre-Cambrian.* By some, these Pre-Cambrian are subdivided into two great divisions, the *Archæan* proper and the *Algonkian,* each of these being again subdivided several or many times. The names of these subdivisions would not mean anything to the beginner, and are therefore omitted here. But it may be worth while to consider briefly some of the characteristics of these Pre-Cambrian rocks in a few typical localities, and to see where they are most typically exhibited.

As these rocks contain practically no fossils, their subdivision has been effected entirely on stratigraphic and lithologic considerations. Even stratigraphy, as ordinarily understood, in the sense of a clearly defined system of bedding, is almost wholly absent; for all these rocks are crystalline and metamorphosed beyond any hope of visible stratigraphic structure. Hence lithologic structure alone is almost the sole guide, except as we can trace (locally) a rude order of superposition between intrusives and the rocks which they have invaded, or between successive sheets of instrusives themselves. Nonconformities (representing crustal movements) and cycles of erosion have also been much depended upon in working out the subdivisions of the great "basement complex"; and the subdividing and naming still goes on.

The Archæan System. The *Archæan* (also known as the *Archæozoic*) rocks are known and described in many countries, outside of North America being found in Norway, Sweden, Finland, China, and Australia. The vast central plateau of Africa is composed mostly of Archæan rocks, as are also the larger part of the peninsula of India, and much of the great mountain ranges of the Himalayas, the Altai, and the Andes, and to a lesser extent, long, narrow belts in the Alps, the Pyrenees, and the Balkans.

In North America, there is first what is called the Canadian "shield," comprising all of Labrador, and all of Northern Quebec and Ontario north of the Great Lakes, and a large strip running north to the Arctic Ocean and east of the Mackenzie River, with the exception of a considerable area around the south shores of Hudson Bay. The name "shield" was given to this area, with similar areas on some of the other continents,

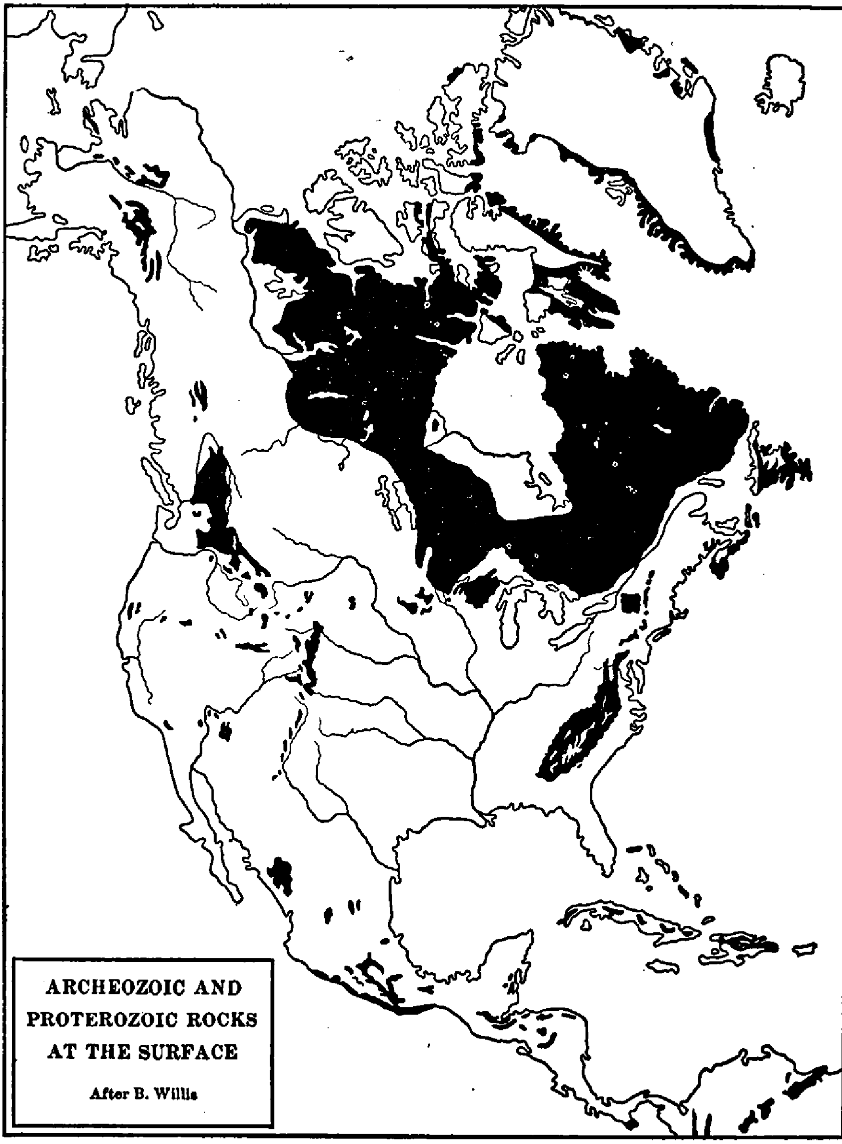

FIG. 202. Map showing the exposures (in black) of the undifferentiated Archæan or Primitive rocks (here termed "Archeozoic and Proterozoic").

because of their fancied resemblance in outline to an immense depressed shield. They are conceived to be the very oldest of the lands, and are thought by evolutionary geologists to have remained more or less continuously above the sea level, while the rest of the areas now comprising the continents have been down under the ocean waters and up again a dozen times since

then. They are always spoken of as the *nuclear areas* of their respective continents, about which the subsequently formed lands have formed; yet they are not thought of as having furnished the sediments for the formation of the other parts of the continents, as these "shields" are spoken of as remaining continuously low in relation to the sea level.

In addition to this large Canadian area of Archæan rocks, much smaller areas of Archæan rocks are found in the Adirondacks of New York, and in the highlands of New Jersey and Southeastern New York. Many scattering areas of granite in the Rocky Mountains are referred to the Archæan, though many such areas of granite and other crystalline rocks here and elsewhere are classed as Cenozoic or Mesozoic "intrusions." In the lower parts of the Grand Cañon of the Colorado are masses of schists and other rocks which are assigned to the *Archæan system.*

Great quantities of *graphite* are found in various ones of the Archæan areas, chiefly among the quartzite schists. Sir William Dawson used to say that there is more graphite disseminated through the Archæan rocks north of Lake Ontario and east of Lake Huron, than there is of carbonaceous matter in the entire coal beds of such areas as England and Pennsylvania. Graphite comprises from 3 to 10 per cent of the Archæan rocks of the Adirondacks, and near the northwestern part of Lake George are "alternating layers of graphitic schists from 3 to 13 feet thick, and the appearance is that of a fossil coal bed." (Schuchert.) As all of their original structure is obliterated from these beds, it is quite impossible to tell what may have been the materials from which these graphites were formed.

Immense quantities of iron ores and limestones are found among these ancient rocks; but it is quite useless to speculate about their supposed origin through primitive forms of life, merely because limestones are now being formed by various kinds of plants and animals, and even iron ores are being produced by the iron bacteria. It is quite essential to suppose that there were at one time large quantities of these substances on the earth which were *original* or *primitive* in the proper sense of these words; and it is to be expected that whenever such substances are found among the Archæan rocks, they will prove to be among crystalline and metamorphic surroundings.

"It is estimated that the Archæan rocks form somewhat more than one fifth of the land surface of the earth, and there is reason to believe that they are actually universal, and that a boring made at any point, if sufficiently deep, would encounter them. They are found at the bottom of many deep cañons, and borings frequently penetrate them at points where there are no surface indications of their presence. If these rocks are really distributed over the entire globe, they are the only formation of which this is true."—*Scott.*

In many different parts of the world, these Archæan rocks are found to be divisible into *two* quite distinct series, the one of schistose rocks composed of highly metamorphosed sedimentary rocks with some so-called volcanic outflows, and the other composed principally of a gneissoid granite, which seems to be intrusive and therefore later than the former series. From this, some geologists hold that over these large areas in practically all parts of the world, the original lands were "ingulfed and destroyed by a universally ascending magma" (Scott), a conclusion which would accord well with the hypothesis of a great world catastrophe; for this event, if it ever took place, must have resulted in such contortions and displacements of the deeper and more solid parts of the earth's exterior or crust, as would of necessity heat to fusion many parts of these rocks, and thus probably squeeze much of this fused material out upon the surface. The fact that such phenomena have been actually observed in many widely scattered parts of the world among these most ancient rocks, is quite the expected thing, on the basis of a universal world catastrophe.

The Algonkian System. The other great division of the Pre-Cambrian rocks has been called the *Algonkian,* a name which was proposed by the United States Geological Survey to apply to the extensive series of metamorphic and sedimentary rocks lying above the Archæan "basement complex" and below the overlying fossiliferous rocks classed as Paleozoic. The name "is but little used outside of this country and is not universally employed even here, but it is beginning to make its way in Europe." (Scott.) As usual, these Algonkian rocks have been subdivided many times, the subdivisions being based chiefly on unconformities and on changes in lithologic texture, for fossils are almost entirely absent. However, in the Algonkian rocks observable deep down in the sides of the Colorado Grand Cañon, and also in the Belt series of Central Montana, are a few scanty fossils which are found in the less altered parts of these rocks. These fossils include the tracks of small worms, a few characteristic brachiopods, and occasional fragments of large crustaceans which have been classed as *eurypterids.*

The *Belt series* of Central and Western Montana is a very extensive mass of rocks, said to be 12,000 feet thick, consisting mainly of quartzites, limestones, sandstones, and hard sandy shales. They are named from the Belt Mountains, near the middle of the State; but this name is also applied to similar Algonkian rocks found extensively throughout much of the western part of Montana, and also in Alberta. Most of the

magnificent mountains of the Glacier National Park are composed of Algonkian rocks, though underneath them run the practically horizontal Cretaceous beds, the latter dipping gently under them toward the west from the front of the range, and similar Cretaceous dipping under them from behind, in the North Fork of Flathead River. We shall have more to say later of this striking example of rocks in the "wrong" order.

In the Lake Superior region is another extensive exposure of Algonkian rocks. These comprise highly metamorphosed limestones, quartzites, mica schists, with occasional beds of sand-

FIG. 203. General view of Summit Mountain and neighboring peaks, from Summit Station, Glacier National Park. The upper strata are Algonkian. The underlying Cretaceous extends part way up the side of the mountain. A closer view is given in Fig. 204. (Stanton, U. S. G. S.)

stones and conglomerates which have not been so indurated and transformed. Sheets of lava and of volcanic tuff also occur. The great copper mines of Lake Superior, consisting of native or free copper, are in amygdaloids and conglomerates distributed over an area 70 miles long by 3 to 6 miles wide. Similar deposits of native copper, "perhaps on a larger scale" (Schuchert), occur east of Great Bear Lake and near the Coppermine River, in the northwestern part of the Canadian "shield." The Marquette iron mines of Michigan, and the Mesaba mines of Minnesota, are in Algonkian rocks, as are also the rich nickel and copper mines of Sudbury, Northern Ontario.

Other extensive areas of Algonkian rocks occur in the Wasatch and Uinta Mountains, in the Black Hills, in isolated areas in Missouri, in Texas, and in the southern Appalachians.

Similar rocks classed as Algonkian occur in Scotland and other parts of the British Isles, in Sweden, in Finland, and in many other countries.

Coarse broken fragmental rocks, which have been called *"tillites"* and have been alleged to be of "glacial" origin, have been found among some

of the Algonkian rocks here and there. But other agencies besides glaciers can distribute deposits composed of coarse angular fragments, which show little or no evidence of stratification; for when water really gets in a hurry, it can pile miscellaneous materials up in a very surprising manner. There are too many evidences of a perpetually mild or warm climate in all these early days of the world, to permit us to think of glaciers as the cause of these few, scanty, and ambiguous deposits called "tillites" by some geologists. And a few striæ or scratches on the rocks of Norway or Scotland or Ontario are not sufficient evidence to warrant us in talking about continental glaciers,

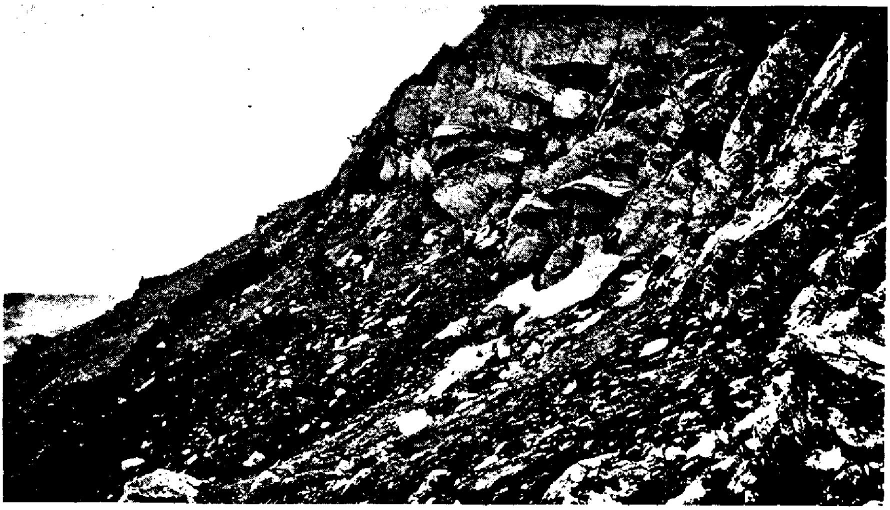

FIG. 204. On the slope of Summit Mountain, Glacier National Park, looking southwest. This shows the line of contact between the Altyn limestone (Algonkian), which lies conformably upon the Cretaceous. This contact is just as normal in appearance as any stratigraphic contact could be. By every law of common sense and true science, we must say that these rocks were laid down successively in the order in which we find them. (Stanton, U. S. G. S.)

in the face of the extensive organically formed limestones in northern latitudes and belonging to the Algonkian series, which give proof of at least a mild climate.

General Remarks. If we consider the Pre-Cambrian rocks as a whole, we may regard them as the *remains of old basement rocks,* which were not entirely obliterated by the erosion and other changes of all the subsequent years. Accordingly we might expect to find occasional traces of life among them, as in reality we do. But on the basis of the ordinary theories, it is extremely difficult to understand how these extensive areas could have persisted in their original horizontal position above the oceans, through all the long millions of years during which the other parts of the continents were down and up a dozen or more times, without receiving thick accumulations of sediments.

Even if these areas had remained above the waters all this time, it is hard to understand why we should not expect to find some traces of the great dinosaurs and other land animals which occur so profusely in other parts of the world. It is acknowledged that these widespread Pre-Cambrian areas, comprising 2,000,000 square miles in the Canadian "shield" alone, have experienced "no pronounced warping or folding" since their original elevation above the ocean and their leveling to the present peneplain, which is in most places "a close approximation to this ancient land surface." (Schuchert.) Yet, over this vast area, there are practically no traces of the sediments or the fossils of any of the "subsequent" "ages."

The following words show how one of the most illustrious of living geologists meets this difficulty:

"It is of common occurrence on the Canadian shield to find the Archæozoic [Pre-Cambrian] formations overlain by the almost recent Pleistocene glacial deposits, and even these may be absent. It appears as if in such places no rocks had been deposited, either by the sea or by the forces of the land, since Archæozoic time; and yet geologists know [I wonder how they know! G. McC. P.] that the shield has been variously covered by sheets of sediments formed at sundry times in the Proterozoic, Paleozoic, and, to a more limited extent, in the Mesozoic."— *Schuchert, "Textbook of Geology," p. 569; edition of 1915.*

We are on surer ground, and no such distorting cloud of theories will obscure our vision of the real facts, if we speak of the actual characters and the methods of occurrence of these Pre-Cambrian rocks. I quote again from another prominent teacher of the science in one of the large Eastern universities, these remarks referring to the Archæan rocks proper:

"In all the continents they form the foundation upon which the oldest fossiliferous sediments were laid down, and, in brief, they are the oldest, the thickest, the most widely distributed, and the most important of all the accessible constituents of the earth's crust. Their uniform character, wherever found, the extreme plication and metamorphism which they have undergone, and their world-wide distribution, are all extremely remarkable features, such as recur in rocks of no other age."— *Scott, "Introduction to Geology," p. 544.*

As a whole, these basement rocks, called Primitive, or Archæan, are very generally *crystalline,* and are composed of such rocks as granite, syenite, gneiss, various kinds of schists, and crystalline limestones. In some places, however, they consist of *hardened conglomerates, gritty sandstones,* and *slates.* There is no necessity to suppose that they should always be

crystalline, or, indeed, that they must always be indurated. It is quite probable that large amounts of strata already included among some of the other and later formations *may in reality be Primitive;* for in all these formations are many rocks which contain no fossils, which probably never contained any fossils, and which are so situated that it is quite impossible to prove the existence of any fossiliferous rocks stratigraphically *below* them.

It is a very singular fact that these Primitive rocks should be found so extensively uncovered in the *northern* portions of so many lands. We have already spoken of their wide exposure in the northern parts of North America and Europe. But it is almost equally true of South America, and of Northeastern Asia; and a large part of the interior of Africa is also composed of the Archæan rocks from which all the subsequent formations have been stripped away. Just why this should be so, is not very clear; nor is it clear just what meaning should be attached to this singular fact.

CHAPTER XX

The Paleozoic Group—The Cambrian System

The Paleozoic group is usually divided into six systems, as follows:

	Systems	*Types of Life*
Paleozoic Group	Permian	Amphibians and Lycopods
	Carboniferous	
	Devonian	Fishes
	Silurian	
	Ordovician	Higher Invertebrates
	Cambrian	

As stated in a previous chapter, such lists of geological systems are always to be *read from the bottom upward,* corresponding to the position which they are supposed to occupy in the earth.

Methods of Correlation. Beginning with the Cambrian system, we find the strata far less disturbed than is the case with the older, primitive rocks; and we also find an abundance of fossils. This enables us to correlate even the subdivisions of these various systems from all parts of the world. The Cambrian, for instance, is divided into a Lower, a Middle, and an Upper series; but many of the same genera of many types of Cambrian life are of cosmopolitan range. The older, Pre-Cambrian, or Primitive rocks could not thus be correlated in detail all over the world, because they contain practically no fossils; and they can be identified chiefly and most surely by their relationship to the overlying fossiliferous beds. For, throughout the entire world, wherever they have been seen and examined, there is always a marked *unconformity* between the Pre-Cambrian, or Primitive rocks, and whatever fossiliferous beds happen to lie above them. It is only occasionally that such overlying beds can be classed as Cambrian. Very frequently *these overlying beds may contain fossils which necessitate calling them Devonian, Cretaceous, or Tertiary, as the case may be.* But in case these rocks lying above the "basement complex,"

or the Algonkian, contain certain fossils peculiar to the Cambrian system, these beds are then *called Cambrian,* no matter what other characters they may exhibit in the way of texture or lithologic composition. The characteristic fossils of the Cambrian which make such identification possible, will be mentioned presently.

Large amounts of space, often equaling a half of the total, of the current geological textbooks and treatises, are devoted to picturesque accounts of alleged "uplifts," "depressions," "revolutions," and "disturbances," of the ancient land surfaces, with descriptions of the migrations of the ancient floras and faunas, the authors of such books being apparently sublimely unconscious of the utter incongruity of such fantastic speculations in any work professing to deal with scientific facts. At any rate, the present author can not have the heart to undertake any such fairylike excursions into the unknown and unknowable, but must content himself with prosaic statements regarding the present *occurrence* or *distribution* of the various ancient rocks, their *characters,* and their *fossil contents,* with such scanty inferences regarding ancient conditions as may seem inevitable in view of the facts as we now know them.

Fig. 205. The Rev. Adam Sedgwick (1785-1873), former professor of geology at Cambridge University.

Divisions of the Cambrian. All of the rocks classed as "older" than the Coal Measures were for many years left undivided, and grouped together under the general name of *graywacke,* or *transition rocks,* and had not been explored by geologists. However, about the year 1831, Sedgwick and Murchison began the study of these transition rocks, with the result that they were soon subdivided. The name given to the "oldest" of these divisions by Sedgwick was *Cambrian,* from the old Latin name for Wales. Although much heated discussion was indulged in between these two men regarding the matter of subdividing these rocks, this name has persisted down to our time and has become firmly established as applying to the lowest division of the true fossiliferous series. However, this division is now subdivided as follows:

1. Lower Cambrian, Waucobian series, *Olenellus* fauna.
2. Middle Cambrian, Acadian series, *Paradoxides* fauna.
3. Upper Cambrian, Saratogan series, *Dikellocephalus* fauna.

Distribution

In America. In a general way, as already remarked, the Cambrian rocks may be found near the Archæan areas; that is, they prevail near the northern boundary of the United States, especially the eastern part. They are not exposed at the surface over large areas, being often buried deeply under other sediments. They occur in disconnected outcrops from the Adirondacks to Newfoundland, and in many other spots southward from the St. Lawrence to Alabama. They occur in somewhat large areas in Wisconsin and Missouri, while small outcrops of them are found in Texas and in various parts of the Rocky Mountain region. Cambrian strata outcrop in the Grand Cañon of the Colorado, but their extent in this locality and in the numerous others just mentioned is largely a matter of conjecture.

FIG. 206. Roderick Impey Murchison (1792-1871), pioneer geologist, and the one who named the Silurian, Devonian, and Permian systems.

Evolutionary geologists always take it for granted that if the overlying Mesozoic and Cenozoic strata could be removed from the rest of these countries, and the other strata of the "later" Paleozoic could also be removed, we should probably find the Cambrian beds spread out over practically all of the continents, next to the Pre-Cambrian. But this supposition is wholly imaginary, and is quite out of harmony with what we know of the extremely *limited areas* of all the other formations that we can actually get at and examine. It is merely a relic of the old onion-coat theory of Werner, and is unworthy of a place in a modern textbook of geology.

Moreover, it should be noted that there are several instances where Cambrian rocks do *not* occur thus next to the primary or primitive rocks. In many localities in the eastern ranges of the Rockies north of the middle of Montana, great areas of Paleozoic rocks are found comprising the mass of the mountains, but resting upon Cretaceous beds which underlie them in a more or less horizontal position. Some of these upper rocks are called Algonkian, as mentioned in the preceding chapter; but some of them are also classed as Cambrian, while others are classed as Permo-Carboniferous. Doubtless some day, under

a more rational system of classifying the rocks, most or all of these upper beds will be classed together under some common name; for they have many physical and lithologic characters in

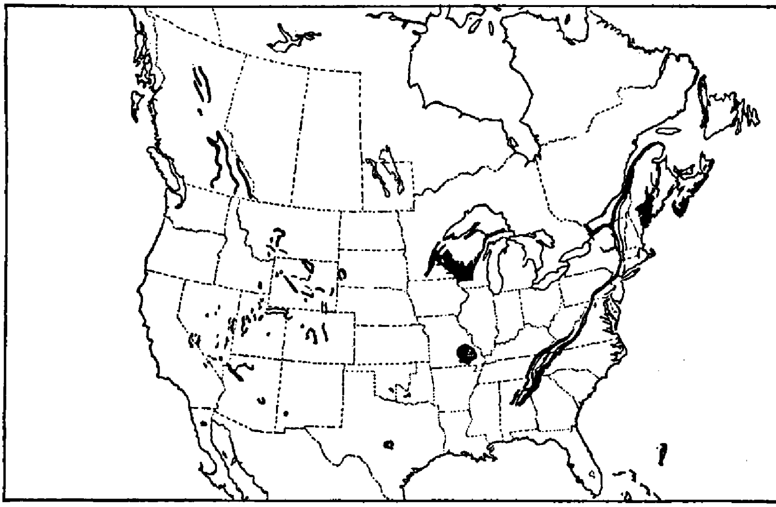

FIG. 207. Map of known Cambrian outcrops in the United States and Canada. (After W. B. Scott, "Introduction to Geology," permission of Macmillan Co.)

FIG. 208. Erosion remnant, composed of Cambrian sandstone, "Driftless Area," Wisconsin. (Alden, U. S. G. S.)

common, and they all seem to rest equally upon the great basal shales of the Cretaceous system which run underneath them from all sides like the soil under a building.

Foreign. In Europe are many extensive exposures of Cambrian rocks. The largest exposures and the thickest beds occur

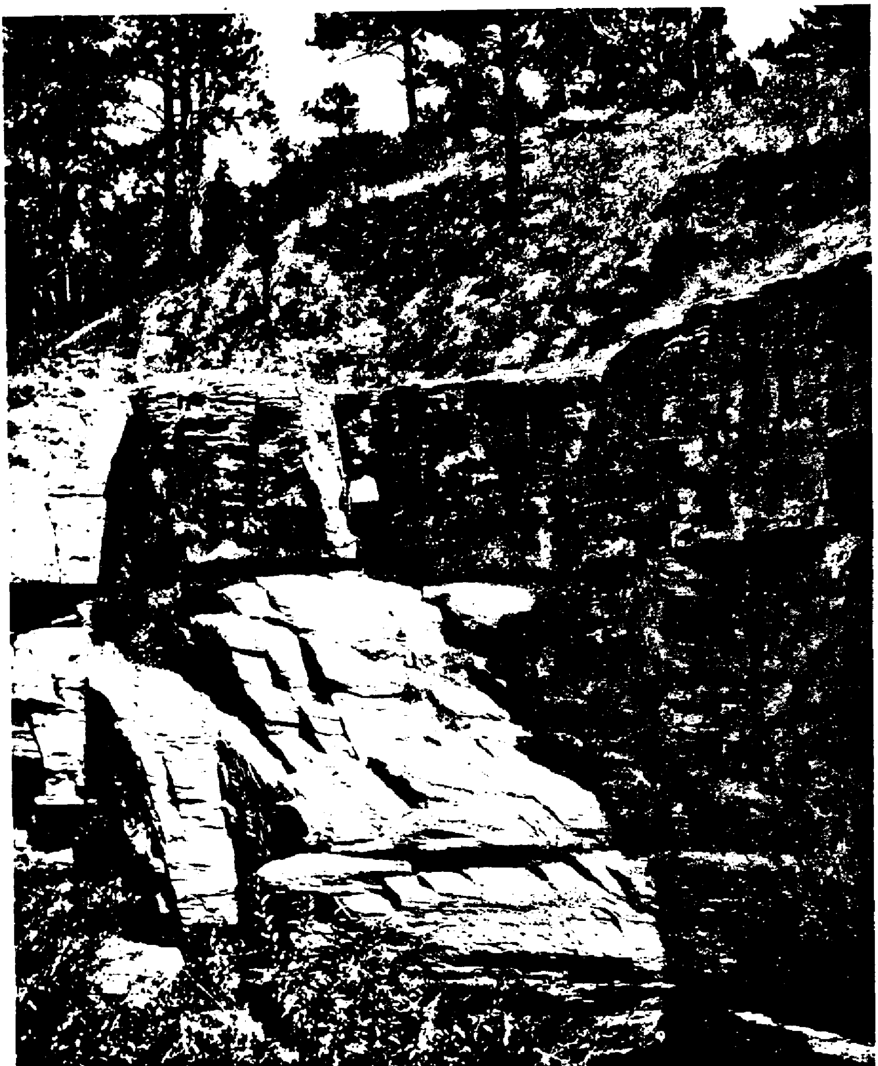

FIG. 209. Deadwood sandstone (U. Cambrian) resting on crystalline schists (Archæan), in Cold Brook Cañon, 4 miles southwest of Wind Cave, South Dakota. (Darton, U. S. G. S.)

in Wales and Spain. In the former country, they are alleged to attain a thickness of some 20,000 feet, and comprise conglomerates, sandstones, shales, and slates. There are considerable areas of Cambrian rocks in Sweden and in the part of Russia around the Baltic province and near Petrograd. But here they are only about 400 feet in thickness, while the beds still remain in their original horizontal position, and consist of blue clays

which are scarcely hardened, and sands containing a few Cambrian fossils, the sands being still loose and incoherent. These are regarded as very striking peculiarities in beds which are considered so *very, very old;* and it is one of the astonishments of geology as currently taught, how these very ancient beds can have come down to us in this quiet way, with the strata still horizontal and showing so little the hardening processes of time. They look as young as the very youngest of the fossiliferous rocks elsewhere.

Other areas of Cambrian beds are found in France, Germany, Bohemia, Spain, and other parts of Europe. Large areas in Eastern and Northern Asia are occupied by Cambrian rocks.

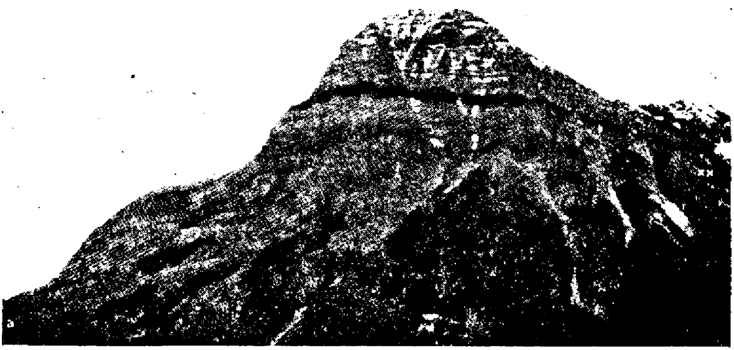

FIG. 210. Mount Stephen, British Columbia. The upper part of the mountain is formed of Middle Cambrian limestones, interbedded with which is a bed of shale that has become famous for the fossils found in it. This bed is shown at *xx;* and the fossils are most wonderfully preserved. (After Walcott.)

They also occur in Northern India, in the south of Australia, and in Tasmania. But strangely enough, no Cambrian rocks whatever have been discovered anywhere in Africa, or in South America, except in one or two small localities in Northern Argentina.

One of the best-known rocks of the Cambrian system in North America is the so-called Potsdam sandstone, which in many localities is used for building material. These sandstone beds sometimes contain ripple marks, mud cracks, and occasionally even tracks of animals, and are usually quite regular in their bedding. Such evidences of shallow-water formation occur here and there throughout many of the fossiliferous groups; but they are often overemphasized by geologists. The great magnesian limestone of Missouri and some other parts of the Mississippi Valley is composed in part of Cambrian rocks, as are also the celebrated "Pictured Rocks" in the sandstone near

FIG. 211. Dr. Charles D. Walcott and Mrs. Walcott, fossil hunting on the side of Mount Stephen, British Columbia. Middle Cambrian.

Carp River, Northern Michigan. Some of the rocks near here have been already referred to as producing great quantities of copper ore; but they are classed as belonging to an "older" series.

Cambrian Life. The fossils of the Cambrian rocks are *all marine.* A few seaweeds are found, and the calcareous accumulations of some of these may have contributed greatly to the making of some of the limestones. But no land plants are known from these beds. The animals are invertebrates, and include sponges, corals, pelecypods (lamellibranchs), gastropods, pteropods, cephalopods, with numerous trilobites and other crustaceans. The most characteristic types of life are the brachiopods and the trilobites.

Foraminifera "very like those of the modern seas" (Scott) are of common occurrence, and siliceous sponges are also found. These forms may or may not indicate deep water.

Of the Cœlenterata, a remarkable extinct group known as *graptolites* are found in the Cambrian rocks, but do not occur in any except the lower divisions of the Paleozoic group. Or, to state the matter another way, any rocks containing graptolites are always classed as belonging to the lower parts of the Paleozoic. These graptolites were somewhat similar to our Hydrozoa, or jellyfishes; but they seem to have had horny internal skeletons, which have been left in great numbers as curious-looking marks like the branches of trees or various fantastic objects embedded in these ancient rocks. Some of these graptolites have been found in practically all parts of the world; that

FIG. 212. Panorama looking along the east side of Labarge Mountain, Uinta County, Wyoming, showing Cambrian lying on top of Cretaceous (coal-bearing). The rounded hills in the middle distance are also Cretaceous. All the beds have steep westerly dips. (Stanton, U. S. G. S.)

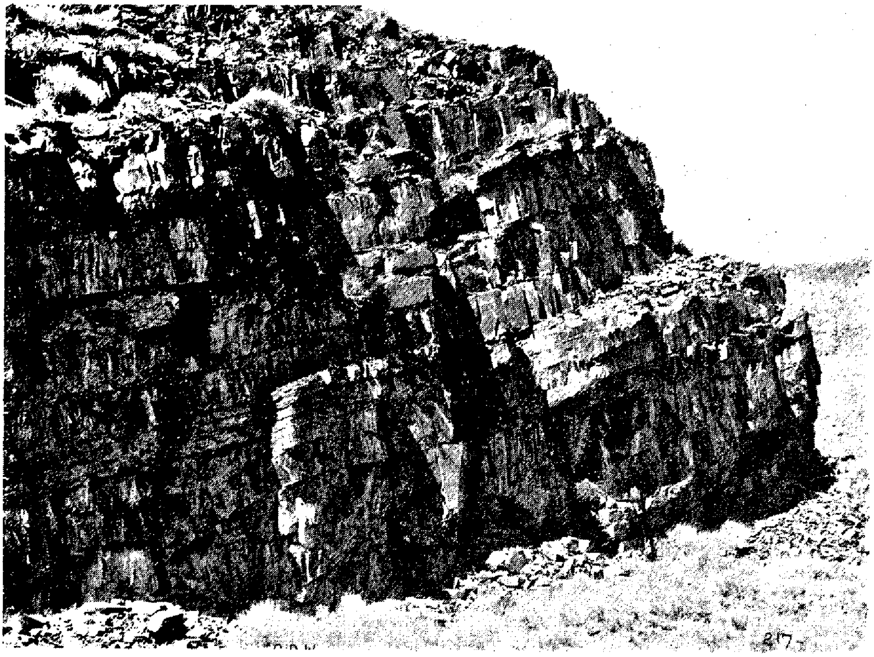

FIG. 213. Lower Cambrian quartzites, with thin beds alternating with thick. The thick beds show vertical cleavage or jointing, while the thin beds do not. Inyo County, California. (Walcott, U. S. G. S.)

is, a special variety (*Dictyonema*) is of almost world-wide distribution. And of course this is considered a very fortunate circumstance by geologists, as it makes this species *a splendid "index fossil,"* enabling them to correlate the rocks in which it occurs, whether in Spain or Australia or Northern Canada. What is really proved by this correlation?

The corals which are found in the Cambrian are of the order known as *cup corals*, and probably lived, as do many of the modern corals, as single individuals and in comparatively deep water. They seem to have been sufficiently abundant in some parts of the Western States to form distinct reefs, but their habits of life are not known. Many of our modern cup corals live in the deepest parts of the ocean.

Of the Arthropoda, by far the most abundant are the members of the great group of *Trilobita*, which are entirely confined to the Cambrian and the other systems of the Paleozoic. They occur in the Cambrian rocks in a great variety of forms and sizes; but they are of so much importance that they will be discussed at greater length in the succeeding chapter.

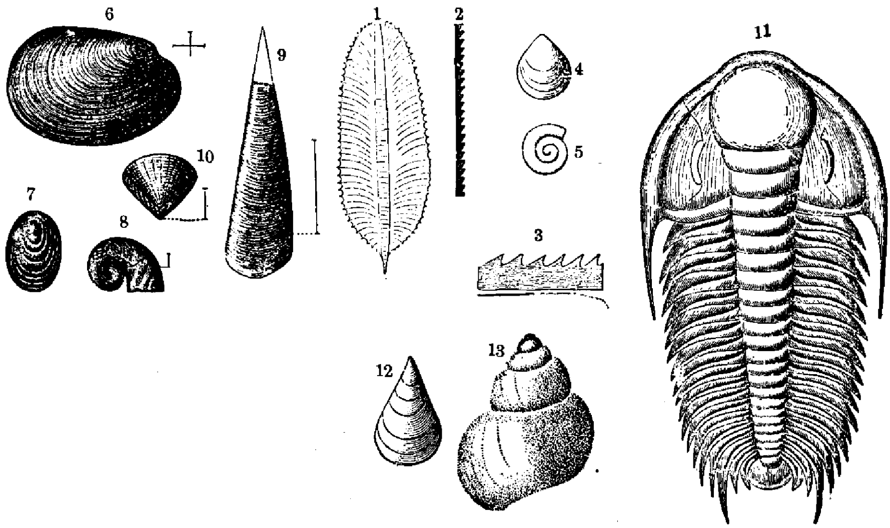

FIG. 214. CAMBRIAN FOSSILS
GRAPTOLITES: 1, *Phyllograptus typus;* 2, 3, *Graptolithus logani.* BRACHIOPODS: 4, *Lingula prima;* 12, *Lingulepis antiqua.* PELECYPOD: 6, *Fordilla troyensis.* GASTROPODS: 7, *Stenotheca rugosa;* 8, *Platyceras primævum;* 13, *Holopea sweeti.* PTEROPOD: 9, *Hyolithes americanus;* 10, operculum of same. TRILOBITE: 11, *Paradoxides harlani* (× 1/6). (After Dana.)

Various kinds of brachiopods are among the most abundant of the Cambrian fossils. They belong to two great groups: the *Inarticulata,* with shells of two valves which are not connected together by a hinge, these shells being mostly horny; and second, the *Articulata,* which have calcareous shells joined by a very beautiful and elaborately constructed hinge. The latter order becomes much more important in some of the beds which will be subsequently considered, in which they "are found in incalculable numbers." (Scott.) But these brachiopods also will be considered more at length in a subsequent chapter.

The principal divisions of the great group of Mollusca are also represented in the Cambrian rocks. The pelecypods (bivalves) are usually small and not numerous. The gastropods occur rather infrequently, while other forms referred to the pteropods, and still others which are referred to the cephalopods, have also been recognized in the Cambrian rocks. All of these types of shellfish will be described in greater detail in a subsequent chapter.

Peculiar Facts. Some of the peculiarities connected with the occurrence of these types of life in the Cambrian rocks should be noted in this chapter. Only a few of these striking peculiarities can be noted here.

Many of the sandstones abound in a small shell about the size of a finger nail, related to the modern gastropod, *Patella*. Another gastropod, *Platyceras primævum*, has a spiral top like a broad horn (Fig. 215), and, "according to some authors, is not generically distinct from the modern genus *Capulus*." (Dana.) It seems to skip all the formations from the Triassic to the modern.

FIG. 215. *Platyceras primævum*. (Walcott.)

Evolutionists are justly surprised at the sudden appearance, in the lowest Cambrian rocks, of so many different species of quite highly organized animals, with only the most scanty evidence of any other lower and more embryonic forms of life having preceded them. And this is notwithstanding the fact that these various fossil beds occur in such detached localities that their arrangement into a series is a purely arbitrary and artificial arrangement; so that *geologists have had their pick of all the suitable rocks in the world with which to begin their series*. The striking way, however, in which a large variety of types of life spring *suddenly* into existence, in spite of the best attempts at arranging them so as to make it seem a more gradual process, is thus commented on by that pioneer of American geology, Professor James D. Dana:

"The Lower Cambrian species have not the simplicity of structure that would naturally be looked for in the earliest Paleozoic life. They are perfect of their kind and highly specialized structures. No steps from simple kinds leading up to them have been discovered; no line from proto-

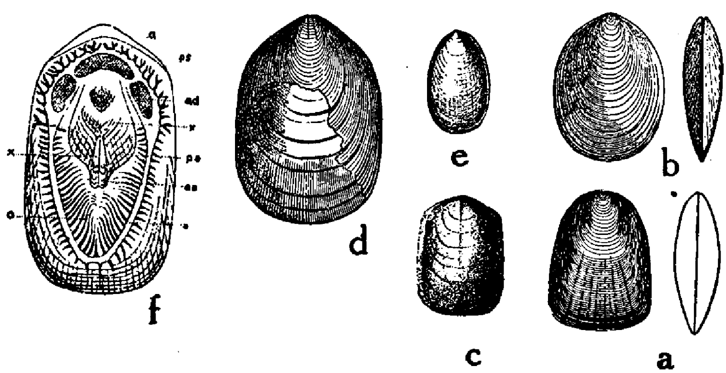

FIG. 216. A group of Paleozoic Linguals. *a*, *Lingula eva* (Black River); *b*, *L. rectilateralis* (Trenton-Lorraine); *c*, *L. modesta* (Trenton-Lorraine); *d*, *L. coburgensis* (Trenton); *e*, *L. ligea* (Hamilton-Portage); *f*, *L. elderi*, interior of dorsal valve, showing muscular and vascular markings. (After Whitfield.) *d*, Divaricator muscular scars; *ad*, adjustor muscular scars; *pa*, posterior adductor scars; *a*, *a*, anterior adductor scars; *x*, *x*, track of advance of the muscular scars; *s*, great pallial sinuses; *ps*, posterior course of the latter; *o*, inner ramifications of the sinuses. (After Whitfield.)

zoans up to corals, echinoderms, or worms, or from either of these groups up to brachiopods, mollusks, trilobites, or other crustaceans. This appearance of abruptness in the introduction of Cambrian life is one of the striking facts made known by geology."—*"Manual,"* p. *487.*

Two genera of brachiopods, *Lingula* (Fig. 216) and *Crania* (Fig. 217), have come down to us unchanged from these Cambrian rocks. They are regarded as wonders in the way of persistence. *Discina* and *Rhynchonella* (Fig. 250, 9), two other brachiopod genera, are also represented in the modern waters; but they occur also in the Mesozoic. It is not quite clear, from the published literature on the subject, whether or not these creatures are found in all of the so-called "subsequent" formations. A few examples of them may be found here and there, but it is certain that they *skipped* nearly all of these great groups of rocks which have been supposed to represent the many millions of intervening years.

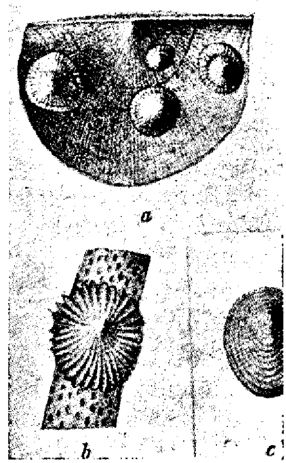

FIG. 217. *a*, *b*, Crania (*a*, *C. lælia* attached to *Strophomena*, Upper Ordovician; *b*, *C. pulchella*, attached to a bryozoan). (After Hall and Clarke.)

Another example of skipping one of the minor subdivisions of the Cambrian rocks is alluded to by Dana, when he says, "The absence of lamellibranchs in the Middle Cambrian, although present in both the Lower and Upper, means the absence of fossils from the rocks, not of species from the faunas." ("Manual," p. 488.)

But it may be asked, Why then are the types of life that are represented in the Middle Cambrian rocks regarded as representing *all* the types of life which *existed during that period in any part of the world?*

The lesson to be drawn from these and similarly related facts will be considered in a subsequent chapter.

CHAPTER XXI

The Trilobites

Systematic Position and History. The Trilobita constitute a subclass of the Crustacea, which are a class under the phylum Arthropoda, the latter containing all the articulated and segmented animals, such as the crustaceans, insects, scorpions, and spiders. Some 2,000 species of trilobites have been described, all from Paleozoic rocks. They have been so minutely subdivided that they constitute some of the most important "horizon markers" or "index fossils" for distinguishing the formations.

"Trilobites were the first fossils to arrest the attention of naturalists" (Schuchert), Edward Llwyd, the curator of the Ashmolean Museum at Oxford, having first described an entire specimen in 1698. Linnæus, the Swedish naturalist, first recognized their relationship with such animals as shrimps, crabs, and lobsters. The name *trilobite* was proposed by Walch, in 1771, and soon came into general use. But for nearly another century, very little was known about the anatomy of these creatures, until their legs were discerned by Billings and Walcott, and finally the antennæ and other features.

General Structure. The name *trilobite* means, *having three lobes,* and refers to the three longitudinal lobes seen on the dorsal or upper side of most of these animals. Their bodies were segmented, the segments being grouped into three divisions, and united on the upper side into a shell or *carapace,* which is the part usually found as a fossil. The shell on the under side was very thin; and this, with the delicate legs and antennæ, is seldom found preserved except in black shales more or less impregnated with sulphur. The carapace also was quite thin, and was made of *chitin,* a substance like the exoskeleton of insects, and more like hair or horn than like bone. It is a nitrogenous substance, somewhat impregnated with lime salts. But it resists chemical change much better than bone, or than the shells of such animals as oysters, clams, and brachiopods; and on this account, the remains of trilobites are very often well preserved.

Habitat. Trilobites lived only in the seas and oceans, probably in rather shallow waters, though of this latter fact we are not absolutely certain. They were probably carnivorous, or scavengers, feeding on the minute forms of life of the bottoms of the seas and oceans. They are found in almost all kinds of marine sediments, though chiefly in limestones and shales, that

is, in the finer sediments. Some of the trilobites may have been good swimmers; but their structure and their habits of life rendered them *very helpless* in the presence of any disturbance of their habitats which would fill the waters with falling particles of mud or sand. When any such unusual sedimentation occurred, they seem to have perished in millions; and quite evidently most of the complete specimens which we find were *buried alive.* They are found in practically all parts of the

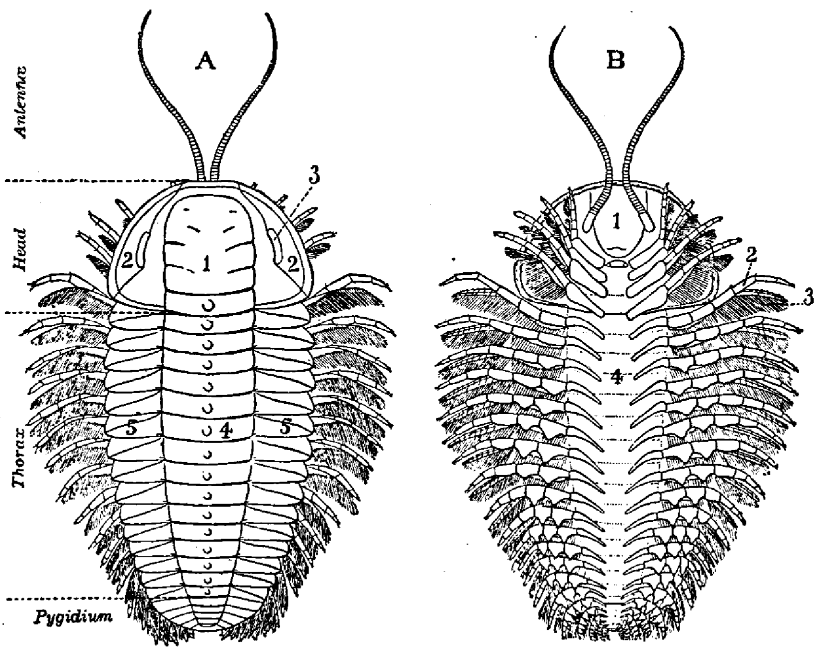

FIG. 218. Outlines of a complete trilobite (*Triarthrus becki*). A, dorsal or upper side of carapace, showing the three lobes, the antennæ, axis (4), glabella (1), and free cheeks (2), and eyes (3). *B,* ventral or under side, showing limbs, and the upper lip or hypostoma (1) which covers the mouth. (After Beecher.)

world, the strata in which they are found being always classed as Paleozoic. They evidently did not live in the waters where vertebrate fishes were common, as the two types are seldom found together.

Geologic Distribution. The following table serves to show the relative proportions of species and genera in the various Paleozoic systems, and it should be remembered that rocks are assigned to the one or the other of these systems *largely according to the number of trilobites* which they happen to contain, together with the variations in the forms and characters

of these trilobites themselves, the more elaborately constructed types being assigned to the Silurian and Devonian, and the more generalized or "primitive" types to the Cambrian or Ordovician.

System	*Genera*	*Species*
Devonian	20	105
Silurian	30	485
Ordovician	80	950
Cambrian	55	300

In size, the trilobites range from minute forms less than half an inch long up to giants 27.5 inches in length; but the average size was about 1.5 inches. Specimens of 3 inches or 4 inches are common, and some even of 6 inches are far from rare; while the very large ones were quite unusual, and the very largest ones are based on restorations made up by piecing together parts of separate individuals, and even fragments from (possibly) scattered localities.

The modern sow bugs or pill bugs which are found in cellars and in damp places, can roll themselves up into balls, with the carapace alone exposed. It is supposed that most of the trilobites could do the same. This would be but a partial protection at best, and did not serve to deliver them from that which seems to have been the real cause of their extermination, namely, being buried alive under rapidly accumulating sediments.

Anatomy. The carapace of the trilobite is divided into (1) the *cephalon,* or head portion; (2) the *thorax,* made up of a series of segments; and (3) the *pygidium,* or tailpiece, also called the abdomen.

In the middle of the cephalon is the *glabella;* and on either side of the latter are the *free cheeks,* each of which bears a compound eye. In some varieties, each free cheek is separated from the glabella by a faint raised line, called the *facial suture;* and this division often causes the parts to separate after death, resulting in imperfect fossils. Some kinds of trilobites are called *blind,* because no eyes have been discovered. In most instances, the compound eye is covered by a single cornea, through which the individual lenses underneath may or may not be visible to us. In a few varieties, each lens had its own cornea. "The number of lenses in a compound eye may vary from fourteen to the astonishing number of fifteen thousand. Imagine an animal with thirty thousand eyes." (Schuchert.)

The number of segments in the thorax is constant in the adults of each species, but varies in the young specimens, and

also varies with the different genera. Two is the least, and twenty-nine the greatest number known, the largest number of segments in the thorax usually going along with a small pygidium, or tailpiece.

The *pygidium* consists of from two to twenty-eight segments cemented together, though the demarcations between them are not always discernable.

On the ventral side was a mouth, covered by an upper lip, called the *hypostoma,* the latter being fastened like a flap to the margin of the glabella above. A pair of *antennæ,* or touch organs, are to be seen occasionally at the sides of the hypostoma; though these antennæ were not discovered until trilobites had been studied for many years. Many pairs of legs are occasionally seen; and it is thought that such appendages were always present, even where no trace of them can be discerned. Many of these new parts have been discovered only by studying extremely thin sections under the microscope.

Molting. It is considered that trilobites periodically shed their chitinous shell, just as crabs and lobsters now do, this shedding of the shell, or *molting,* as it is called, occurring more frequently during the early growth of the animal, but occasionally during the entire life. The growth or development of these creatures has been traced out by much patient observation, and is almost as well known as if the living creatures were available for study.

Relationship. Much speculation has been indulged in as to the relationship between the trilobites and the other crustaceans. Except for mere matters of anatomical comparison, such speculations are valueless and quite unscientific; for there is no way of proving that any of our modern forms are in any way genetically related to these creatures. Speculation also as to the historical order in which the different forms of trilobites themselves appeared and disappeared, is useless, and always involves a *reasoning in a circle;* for certain varieties are called the "oldest" because of having what are called generalized or "primitive" characteristics; and then the more specialized kinds, which are called "younger," are said to have been derived from the "older" kinds, because they are more specialized!

Locally, of course, certain beds containing one type of trilobite can be shown to lie stratigraphically above another, and thus can be shown to have been buried in this locality *after* the other; but the theory that *all over the earth,* the one kind lived and died before the other, is absolutely incapable of proof, and

quite unscientific. Such a condition of the ancient world can not even be thought out and imagined, without assuming the entire *onion-coat theory* in its biological form. And then when some people take these assumed successive kinds of trilobites — which is a *purely artificial arrangement,* and in no sense historical — and from the results try to prove how one kind was evolved into some other kind, we must recognize such juggling of the evidence as mere child's play. Yet, for over half a century, this paleontological whirligig has been the leading diversion of people otherwise intelligent and scientific in their habits of thought.

CHAPTER XXII

Fossil Shells

Importance. In sheer point of numbers, fossil shells constitute by far the greater number of fossils found and collected. As here presented, both of the two great groups of shelled animals, the *Mollusca* and the *Brachiopoda,* will be included in our study; and of these classes, about 45,000 species of the true Mollusca are known to be now living, while more than half as many are found as fossils. In the case of the brachiopods, only about 160 species are now living, while the fossil species number at least 7,000, or forty times as many. Indeed, the brachiopods constitute the most important single group of fossils, when considered as mere "horizon markers" or "index fossils."

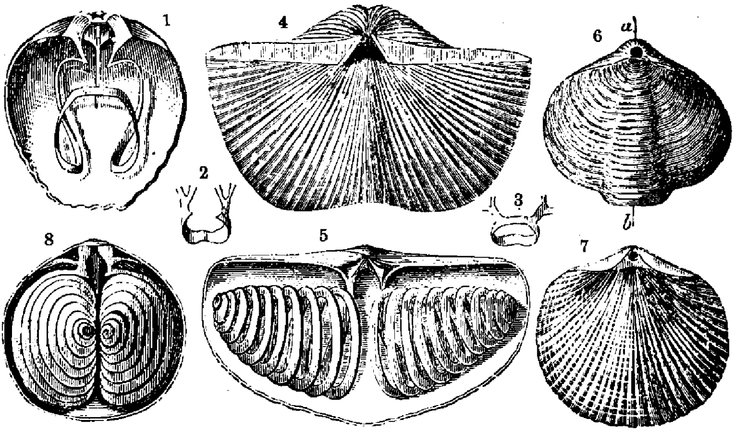

FIG. 219. Brachiopods, showing external and internal features. 1, *Waldheimia flavescens;* 2, loop of *Terebratula vitrea;* 3, *Terebratulina caputserpentis;* 4, *Spirifer striatus;* 5, *the same,* showing interior of dorsal valve; 6, *Athyris concentrica;* 7, *Atrypa reticularis;* 8, *the same,* showing interior of dorsal valve. (After Dana.)

Doubtless it is because of their helplessness in avoiding burial alive in the presence of an unusual condition of sedimentation, that such great numbers of brachiopods are found as fossils in the rocks, a fact which we found to explain the great numbers of fossil trilobites.

Brachiopods or Lamp Shells

Types of Brachiopods. Brachiopods are found as fossils in the Paleozoic and Mesozoic rocks throughout the world. Some few specimens are occasionally found in the rocks classed as Cenozoic, or the Tertiary rocks; but only about 20 kinds have been found in the Cenozoic rocks of North America, and not

many elsewhere. The living genera *Crania* and *Lingula* are regarded by evolutionary geologists as the longest-lived of all the shellfish, for the living ones can not be distinguished from the fossils found in what are called the "oldest" formations of the Paleozoic, the Cambrian. The genera *Discina* and *Rhynchonella* are alive to-day, and are found as fossils in the Ordovician and other systems. The *Terebratulidæ* are a family with 68 living species, and are found as fossils chiefly in the Mesozoic.

Brachiopods are first found mentioned in zoölogical literature in a work published in Rome in 1606; but not until the time of Cuvier was any detailed study of their internal anatomy published, the great French naturalist having published an account of them in 1797. Their embryology and early growth were not understood until about 1860, and even yet these features are not at all well known.

Structure. The body of a brachiopod is inclosed in a bivalve shell, the two valves constituting a *ventral* and a *dorsal* covering, or a top and a bottom, rather than the two sides, as in the mussel, the clam, and the oyster. The latter are true mollusks; and in their internal structure as well as in their shells, the mollusks and the brachiopods are very different.

The word *brachiopod* comes from a word meaning *arm-footed,* and originated because of a wrong interpretation of the brachia, or arms, for these are not used by the animal as feet, as was supposed in the year 1806, when the word was coined. The two arms are looped and rolled into a spiral, and have *two* chief functions: first, to *propel currents* of water through the shell from which the minute food, mostly algæ, can be extracted and passed over to the mouth; second, to serve for purposes of *respiration,* that is, for absorbing oxygen from the water.

In the ventral valve, near the hinge, is found a hole through which, when alive, a fleshy stem called the *peduncle* or *pedicel* grows; this peduncle or pedicel being in most cases anchored to some fixed object, like the bottom of the sea. Thus the adult animals are permanently located for the rest of their lives. But in the developing stage, soon after being hatched, the young creatures swim around freely for a few hours or a few days, until they find a suitable location, when they settle down and fasten themselves permanently to some rock or to the bottom of the sea. The extremely small size of these larvæ, together with the very short time which they spend in this active state, would help to explain why the brachiopods are not very widely distributed, but are *quite localized.* However, when found at all, they are often in astonishing numbers, the rocks in some localities being almost covered with them.

Brachiopod shells are divided into two groups, the *Articulata* and the *Inarticulata,* these divisions being based on the way in which the two valves are articulated or fastened together at the hinge. When the ventral valve has one or more teeth which work in corresponding dental sockets or hinge-lines in the dorsal valve, the specimen is classed as one of the Articulata; when these are not present, it is placed in the other subclass. The shells of the Articulata are usually composed of calcium carbonate; that is, they are *calcareous.* The shells of the others are *phosphatic,* being composed of calcium phosphate. By the aid of a pocket lens, minute holes or canals may sometimes be seen passing through the shell, which is then said to be *punctate;* if these are absent, the shell is *impunctate.*

The shells grow or are secreted by a part of the animal called the *mantle,* which consists of two thin membranes, one fitting to the inside of one valve, and one fitting that of the other. These parts of the mantle are like a second or inside shell, only they are soft, like skins; and besides the work of secreting the outer shell, they act to assist the *brachia,* or "arms," in the work of respiration carried on by the latter.

Condition of the Fossils. On the inside of an empty valve are seen various scars or markings, showing the places where the *adductor* and *diductor muscles* were attached. The former served to close the valve, or to bring the two sides together; the latter muscles were for the purpose of opening the valves. Unlike the shells of many true Mollusca, the shells of the brachiopods do not gape or open after the animal dies. But when the soft parts of the creature decay after death, the *hole* in the beak or hinge region is left open; and then sand or mud can be washed into the empty shell through this open hole. In very many cases, however, perhaps in the majority of cases, the fossil brachiopods are found with *the valves applied or closed, and the interior hollow,* or only filled with minute crystals of calcite, indicating that these shells had been buried while the animals were still alive, or at least before the shells had been exposed to any particular washing or movement of the waters. And when there are found, in various parts of the world, extensive strata containing uncounted thousands of individual specimens of brachiopods, *practically all of them in this condition,* it is hard to understand that these beds were formed under any normal conditions, such as prevail at the present time; because it is a very simple and plain fact that no such rock deposits are now being produced anywhere on earth, so far as we are aware.

Occurrence. During the cruise of the *Challenger*, brachiopods were dredged or brought up at only 38 or 39 out of the total of 361 stations where dredging work was carried on, showing that these animals are extremely localized, or restricted in their geographical distribution, though plentiful where they do occur. They do not seem to be eaten extensively by other animals, nor are they troubled much by internal parasites; their restriction in space and their comparative scarcity in the modern seas, as compared with their abundance in ancient waters, being due, probably, as already pointed out, to the conditions that attend the early growth of the young animals. As all the adults are fast anchored to the bottom or to some large object, they are absolutely helpless in the presence of any great disturbance of the waters which might bring along an unusual supply of mud or sand and so bury them where they are.

Among the modern living genera, *Lingula* and *Glottidia* are found between tide marks or in the shallow waters down to 17 fathoms. Others are found in much deeper waters, at depths ranging from 4,000 feet to nearly 14,000 feet. (Davidson.) *Crania* is usually found at moderate depths down to about 5,000 feet. One species of *Terebratula* was dredged from a depth of 2,900 fathoms, or 17,400 feet, in the North Pacific. But most brachiopods live in shallower water, abounding down to a depth of 3,000 feet or 3,600 feet, though about half of the living species live below the hundred-fathom line, or below 600 feet. *Thus the majority of the living brachiopods live below the edge of the continental shelf,* where no sedimentation or deposit of mud or sand is now going on, and where no true stratified beds are now being made.

However, the total area of the ocean hitherto explored by dredging, forms such a very small fraction of the total, that it is quite premature to speak of the geographical distribution of such creatures as the Brachiopoda, or to dogmatize about what kinds are "extinct"; for the progress of scientific discovery is constantly bringing to light, from almost all the groups of the invertebrates, genera which seem identical with fossil genera which have long been declared to be "extinct."

The Mollusca or True Shellfish

Structure of a Mollusk. The *Mollusca* are soft-bodied animals, with bilateral symmetry, and are represented by the clam, oyster, snail, and pearly nautilus. Most of them have external shells, while some have instead an internal shell or skeleton, and some, like the slugs, have no shell at all, or only a rudimentary

one. Thus a great variety of forms are included under this class. The class name means *soft;* and this is a characteristic common to all, though, as we have seen, there are many other animals to which this description would equally apply.

One noticeable feature of most mollusks is the *foot,* so-called, a flat portion under the creature by means of which it creeps or crawls along. There is commonly a thin, membranous *mantle,* by means of which a shell is secreted. Within the mantle cavity are the *gills,* organs which, by their movements, keep currents of water passing through this cavity, and which extract oxygen from the water as it passes along. In the land snails and slugs, the gills are absent, and respiration is carried on by means of the mantle cavity, which acts as a lung, this cavity being filled with air. The snails and slugs, with most other mollusks except the true bivalves, have a sharp, flexible ribbon, or tongue, called a *radula,* which is made of chitin, and which is armed with minute, sharp teeth, much like a saw, by means of which the animal cuts up its food.

The Mollusca live in a great diversity of habitats. Almost every part of the land, and all the shallower parts of the oceans and the fresh waters, contain them; and in numbers of species, they are surpassed only by the insects, which probably outnumber them 2 to 1.

The Shell. The shell of a mollusk consists usually of three layers. The outer one is very thin, brownish in color, and composed of horny matter. This layer is always absent in the fossil. The thick, main layer of the shell is calcareous, or composed of some form of calcium, and is called the *porcelaneous* layer. This is the part most often preserved in the fossil state. The innermost layer is often quite thick, and is composed of mother-of-pearl, which is a form a calcium carbonate known as *aragonite* and readily soluble in water containing certain chemicals in solution. On this account, this layer is not often well preserved in the deeper rocks, or in the more porous ones.

Classification. Only three classes of mollusks are of geological importance, and these are the only ones which we need to study here. They are the Pelecypoda, the Gastropoda, and the Cephalopoda.

Pelecypoda (or Lamellibranchia)

Structure. The name *Pelecypoda* is derived from words meaning *hatchet-foot,* because the foot is shaped like a wedge or a hatchet. A former name applying to this class is *Lamellibranchia,* derived from words meaning *lamellate* or *leaflike gills.* When looked at from above, one of these animals seems to be

compressed from the sides, the soft parts being covered with a right and a left valve, each symmetrical with reference to the other. Thus these animals are often called *bivalves,* in distinction from the univalves, such as the snails and other Gastropoda.

The *pelecypods* include such common types as clams, oysters, mussels, cockles, and scallops. Some of them live in the fresh waters of the lands; but most of them are marine, and live along the shores of the shallower water, where they find plenty of food, consisting of microscopic algæ and other low forms of life.

The *gills* not only act as breathing organs, taking oxygen from the waters, but they serve also to strain out the food from the water which passes through the mantle cavity in a continual current, passing in through one opening near the posterior end and out through another similar opening near by, these two tubes being called the *siphons.* Many of these animals live more or less deeply buried in the mud or sand; and in such a case, the siphons are large and long, sufficiently so to reach to the top of the mud or sand.

The right and left valves are joined on the dorsal side by a *hinge,* which allows the valves to open and shut. There is always an elastic ligament, either on the outside or on the inside of this hinge, which acts like a spring to keep the valves open when the animals are reposing or feeding. On the inside of the shell, attached to each valve, are one or more pairs of *adductor muscles,* by means of which the animal can keep the valves closed against an enemy for a limited time. But when these muscles become tired, or when to the animal all seems safe and well, the muscles relax, and then the elastic ligament springs the valves apart more or less widely. The hatchet-shaped foot then protrudes through this opening between the valves; and by means of this fleshy foot, some varieties can plow their way through the mud or sand to the distance of a foot or two.

Habits. Some forms, like the oyster, do not burrow at all, but are permanently attached to some object on the bottom. Other forms, like *Solen, Lutraria,* and *Mya,* make quite deep burrows; and in these cases, the valves always gape or spread open quite widely after the animal dies, and even in life these valves have to spread considerably in order to allow the large, fleshy foot to protrude between them. The shells of these burrowing species are always elongated in form.

Occurrence. Pelecypods are not common in the Cambrian, though they are found in the Ordovician rocks; but they are found best preserved in the Pennsylvanian or Upper Carbon-

iferous. To reverse this statement, rocks where pelecypods are abundant and well preserved could not well be called Cambrian; but if the other associated fossils permitted the idea, these rocks would be classed as Pennsylvanian or Upper Carboniferous. Pelecypods, however, are not often used as index fossils in the Paleozoic rocks. In the Mesozoic, on the other hand, they are more common (or *where more common, the rocks are called Mesozoic,* which is the same thing), and are often used as index fossils to differentiate between the systems, Triassic, Jurassic, Comanchean, or Cretaceous. They are plentiful wherever these rocks are found throughout the world. Indeed, Lyell based his division of the Tertiary rocks on the percentage of what he considered to be living or extinct species of Mollusca found in these various rocks, assigning those with a small percentage of "living" species to the earlier divisions, and contrastedly assigning those with a large percentage of "living" species to the later divisions of this system. As we shall see later, this percentage system is quite unreliable and wholly unscientific as a method of distinguishing the relative ages of the formations.

The Gastropoda

Structure. The name *Gastropoda* means *stomach-footed,* and was given because of the fact that these animals crawl around on the fleshy part called the *foot,* which is, of course, on the ventral (stomach) side of the body. This name is almost grotesque in its whimsical meaning; but it has been so firmly established, and for so long a time, that any attempt to displace it with something more expressive would be useless — even if such a name could be invented.

The Gastropoda include the snails, conchs, drills, periwinkles, and limpets, together with the naked and semi-naked slugs of the ocean and of the land. As a class, these animals are quite slow and stupid in their movements, and are most common in the shallow salt waters, though some are also found in the fresh waters. On land, a great variety of forms belonging to this class are found in all parts of the world. The latter are the *pulmonate* or air-breathing snails and slugs, which are often great pests in gardens and greenhouses, their keen *radulæ,* or sawlike tongues, making rapid destruction of many choice and valuable plants in a very short time. Forms not widely different from these are found in the ocean, where their radulæ are used to pierce the shells of other shellfish, from which their name of "drills" has been derived. This drilling of oyster and clam shells is materially assisted by a weak solution of sulphuric

acid secreted by the attacking drill. When a hole is effected, the contents of the victim are sucked up by the drill.

The shell of a gastropod is usually shaped like a spiral which turns toward the right hand, or in a *dextral* direction. Some few kinds are known which turn in the opposite direction. From having only the one shell, they are called *univalves.* Most kinds, however, have a small plate, called an *operculum,* which is attached to the foot, and by means of which the animal can close the opening to its shell after its body has been drawn inside. This operculum is sometimes made of chitin and sometimes of calcium carbonate. It in no way corresponds to the second valve of other mollusks.

Occurrence. Small, hood-shaped gastropods are found in the Cambrian beds. They are common in most of the other systems, many of the fossil forms being so similar to the living ones that it is extremely difficult to tell them apart. When we remember that there are some 20,000 living species named and described, and that they are known to *vary greatly in form with changed environment,* it would seem impossible to tell how many of the modern living species may truly be the counterparts of those found as fossils; for in comparing the fossil kinds with the living ones, *no allowance is ever made for the greatly changed environments between the ancient and the modern conditions.* It would really seem to be quite unsafe and unscientific to base wide general conclusions on the results obtained by such superficial comparisons, when one of the most important factors pertaining to these conditions has been completely neglected or ignored.

The *Pteropoda,* or sea butterflies (also called winged snails), compose a group of small gastropods with thin phosphatic shells, which are found living in the upper parts of the pelagic or open ocean waters. Fossil gastropods are sometimes found in great numbers in certain localities, their remains having given rise to the extensive phosphatic rocks found in Tennessee and elsewhere. The name given to the kinds forming these latter deposits is *Cyclora,* their shells having been left behind after the rest of the limestone in which they were originally embedded has been removed by weathering. These phosphate rocks are very valuable as fertilizers.

Cephalopoda

Form and Structure. The highest group of the Mollusca are the *cephalopods,* a name which indicates that the parts corresponding to the *foot* in other mollusks here acts like a real *head.*

The Cephalopoda include the octopus, the cuttlefish, the squid, and the nautilus, together with the great group of fossil forms known as the ammonites. The *ammonites* (with also the living nautilus) had shells with distinct chambers, the animal living only in the outer apartment, or the vestibule. The squids, the octopus, and the cuttlefish do not have any external shell, though they have a body almost exactly like the first group, and they have also an internal shell or internal skeleton, which is often found as a fossil. Another group, the *belemnites,* are found as fossils only in the Mesozoic rocks, and are entirely extinct, so far as we know. They had thick internal skeletons shaped like a cigar;

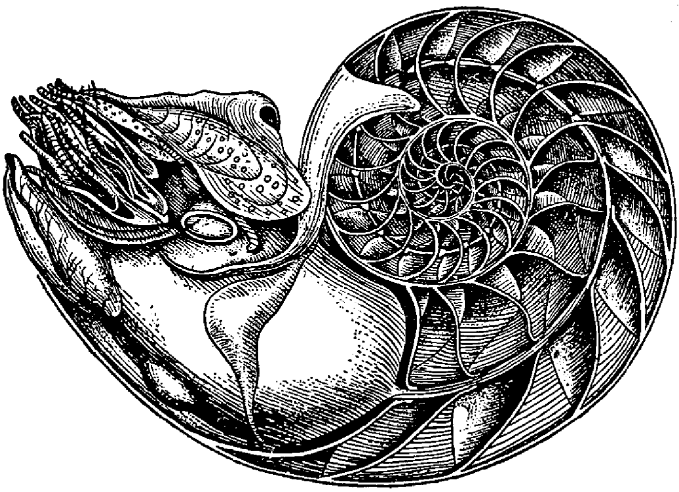

FIG. 220. The pearly nautilus.

and they are very common in the rocks of the Mesozoic group. Here it will be sufficient to speak briefly of the three divisions, the nautiloids, the ammonites, and the belemnites.

The *pearly nautilus* (Fig. 220) is an inhabitant of the open waters of the East, ranging from the Philippines and the Malay region to the Fiji Islands. They are gregarious animals, and live in the warm waters at a depth of from 300 to 600 feet, though occasionally found as deep as 1,000 feet. Their empty shells often drift on the surface of the water to almost all the shores bordering their marine habitats. Some four living species are known, and the shell of these living species is not very unlike multitudes of fossil forms found in the Paleozoic and Mesozoic rocks. Many of the Paleozoic forms had straight

chambered shells instead of coiled ones, some of these straight shells being 15 feet long.

The Ammonites. The beautiful coiled chambered shells of the *ammonites* are among the most characteristic fossils of the Mesozoic rocks. In size, in shape, and in elaborate ornamentation, they almost tax the ingenuity of the naturalist to attempt to describe them, for over 6,000 fossil species have been listed and classified. The shells range in size from 3 inches up to 7 feet in diameter; and if one of these large specimens were uncoiled, it would be about 25 or 30 feet in length. These large, elaborately constructed shells are always assigned to the Mesozoic, usually to the "late" Mesozoic. Full and elaborate lists of types for examples to be used as index fossils have been prepared; and from these lists, it is easy for the expert to assign any particular bed or set of beds to the proper "horizon."

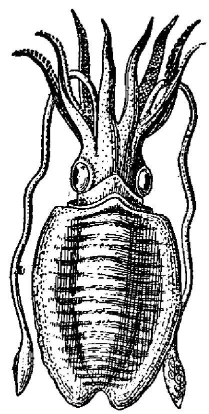

FIG. 221. Living European inkfish (*Sepia officinalis*), viewed from the upper side. Much reduced. The suckers can be seen on the inside of the long arms, as well as on the smaller ones. (After Woodward.)

The name *ammonite* dates back nearly two hundred years, and is in allusion to the ram's horns which were considered to be characteristic of Ammon, an Egyptian deity. "Alexander the Great is represented on the coins of Lysimachus deified, with the horn of Ammon and a diadem." (Edwards.) In India, these fossils are used in certain religious services, and also constitute regular articles of trade.

The ammonites had a more ornamented shell than the pearly nautilus, and often had a distinct keel along the center of the outer whorls. The ammonites probably closed the opening to their shell with an *operculum,* while the modern nautilus does not have any such door to his home. In trying to picture them, we must think of something like a squid or an octopus, with its posterior end and the larger part of its body tucked away inside one of these coiled shells, the arms and all the anterior part being free on the outside. It may be that the entire body could be withdrawn into the shell. In spite of their large, somewhat heavy shells, it is quite probable that the ammonites were good swimmers.

The form and arrangement of the septa dividing the various compartments have been made the basis of an elaborate classification; for as these septa always become more and more complex in pattern with the age of the individual animal, as can be seen by the progressive complexity outward in any individual specimen, therefore (so the evolutionists reason) the more

simple specimens must be *older* than the more complicated ones; and so in this simple fact, we have (so they say) the key to determine the relative age of any given variety. Thus the beds containing any fossil ammonites can easily be arranged in an alleged "chronological" order, based quite largely on this gradual development in the complexity of the septa of these fossil animals. As Professor Schuchert says, it is this structure which "makes these fossils so valuable in deciphering the chronology of Mesozoic time." ("Textbook of Geology," p. 865; edition of 1915.) The puerility of such a method of reasoning seems never to have suggested itself to the minds of geologists since Alpheus Hyatt (1838-1902) first taught it to them.

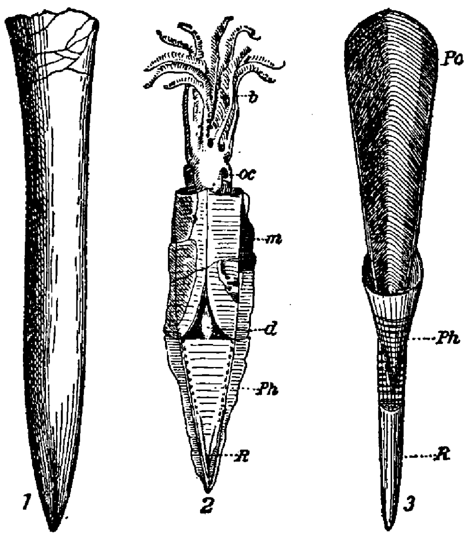

FIG. 222. Fossil cuttlefish (belemnites). 1. A belemnite (*Pachyteuthis acutus*) from the Lower Lias, England. 2. A belemnite (*Belemnoteuthis antiqua*) from the Oxford Clay, England, partly restored: *b*, arms; *oc*, eyes; *m*, mouth; *d*, ink bag; *Ph*, phragmocone; *R*, guard. 3. Restoration of a belemnite's shell: *Po*, proöstracum; *Ph*, phragmocone; *R*, guard. (From "The New International Encyclopædia," by permission.)

The Belemnites. The fossils known as *belemnites* (Fig. 222) are the internal parts of a kind of cephalopod similar to the modern squids or cuttlefishes. In a few instances, the outlines of the soft parts of these creatures have been made out; and from these, we see that the animal had ten arms or tentacles, eight short and two long, as in the modern squid. They had large, well-developed eyes, and had two internal gill plumes, from which circumstance the name *Dibranchiata* has been assigned to them. As in the case of the modern forms, the belemnites had an internal sac containing the famous sepia, long the foundation for so-called India inks. This sepia is brownish black, and mixes readily with the sea water; and in times of danger, the creature squirts some of this fluid into the water in front of it, and under the cover of this original "smoke screen," can make its escape.

The part of these animals usually found is the *guard*, a pencil-shaped, calcareous piece from their internal structure, together with the cuttle bone, and also the *pen*, which was made of chitin. The guards were sometimes 2 feet long and 4 inches thick; while the cuttle bones were some 2 feet long, indicating a length of body for the animal of perhaps 8 feet. The giant squids of our present seas are sometimes 18 feet long, their two longest arms attaining a span of over 30 feet when extended.

CHAPTER XXIII

The Ordovician System

Subdivisions. In Europe, these beds are named *Lower Silurian,* though the name *Ordovician,* derived from the name of an ancient tribe of people who lived in Wales in the time of the Romans, is gradually becoming accepted. Fully 5,000 species of marine invertebrates have been described from the Ordovician rocks, a fact which gives us some idea of the great profusion of life here displayed. The following is the classification of the subdivisions of these rocks, as given by Grabau:

Upper Ordovician or Cincinnatian (including Trenton)	9. Queenston shale 8. Oswego sandstone 7. Lorraine (Pulaski) shales and sandstones 6. Frankfort shales 5. Utica shales 4. Trenton limestone
Middle Ordovician or Champlainian	3. Black River limestones 2. Lowville-Chazy limestones
Lower Ordovician or Canadian	1. Beekmantown formations

In many localities, the Ordovician rocks rest conformably, or without any marked physical break, upon the Cambrian. Occasionally also, as in the case of the *Ozarkian beds* of Southern Missouri, we find sets of rocks which can not be definitely assigned to either the one or the other, being apparently partly the one and partly the other, so far as the contained fossils go. This, however, is only what must be expected, from the very nature of the way in which these geological systems of rocks are made up.

Characters of the Rocks. Limestones greatly predominate in the Ordovician rocks, and dolomites are even more common than ordinary limestones. Sandy and shaly beds occur among the Lower and the Upper series; but the rocks of the Middle series and of parts of the others were evidently deposited in seas where limestones were being made by all kinds of organ-

isms. The *Trenton* limestones of the Upper series have a very wide distribution over the North American continent.

The St. Peter sandstone is supposed to extend over much of the States of Illinois, Iowa, and Missouri, and also parts of Wisconsin, Minnesota, Michigan, and Indiana, with some few places elsewhere. It is a remarkably pure quartz sandstone,

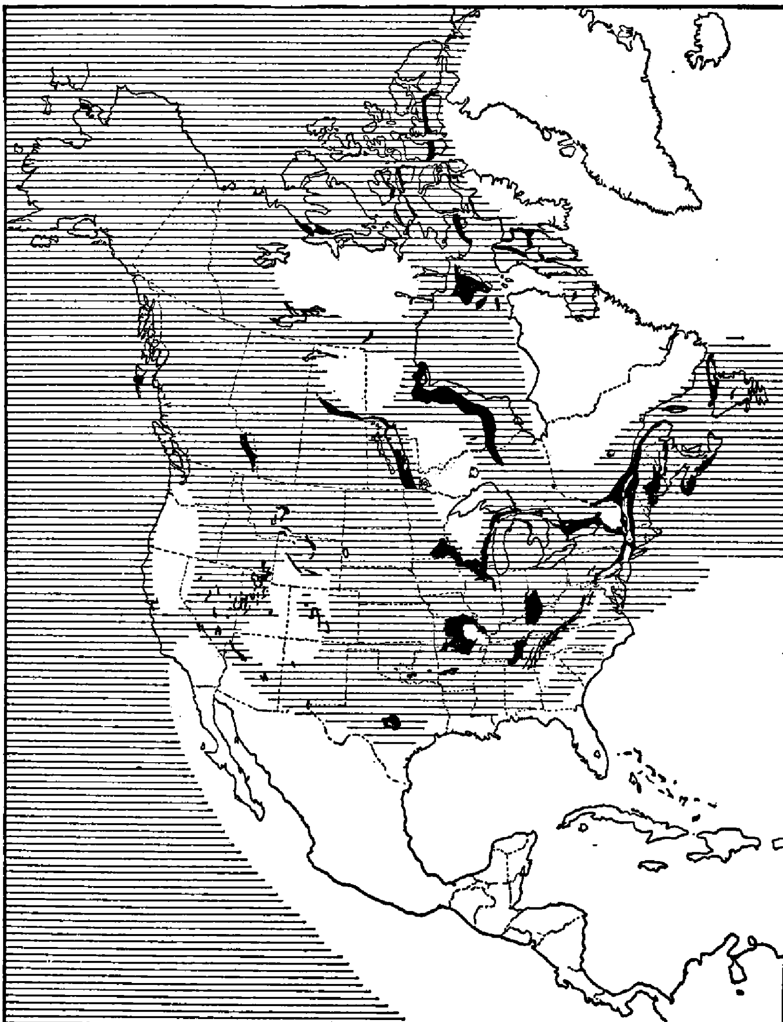

FIG. 223. Map showing the distribution of Ordovician rocks in North America. The black areas represent the known exposures of the Ordovician; the white are the areas supposed by evolutionary geologists to have been land; and the lined areas represent what would be the ocean, according to this theory. (After W. B. Scott, "Introduction to Geology," permission of Macmillan Co.)

FIG. 224. View in quarry of Beekmantown dolomite (L. Ordovician), Williamsburg, Pennsylvania. (Butts, U. S. G. S.)

composed of well-rounded grains of quite uniform size in any particular locality.

The Upper Ordovician consists more largely of shales and sandstones, with some slates and even some conglomerates, the Medina sandstone and the Oneida conglomerate being assigned to this series. These names, as will be recognized, are from the State of New York, where the type formations were first recognized. But when the type formations were thus fixed upon and named from their occurrence in particular localities, then, as exploration was extended, the *same names* would be given to similar rocks found elsewhere, *whether or not any actual stratigraphical continuity could be established between the two localities.* If fossils happened to be scarce, such identification might have to be made largely on lithologic texture, checked up by the associated beds both above and below.

In Europe, the Ordovician rocks occur in two quite separated areas, the *northern* one extending, with interruptions, from Ireland to the interior of Russia, the *southern* one occurring in disconnected patches over much of the southern countries of

FIG. 225. Ledge of outcropping Ordovician slate, north of West Castleton, Vermont. Syncline showing relations of cleavage and bedding. (Dale, U. S. G. S.)

Europe, including some areas in the middle of the continent. Shales and limestones characterize these rocks in Scandinavia, where they are nearly horizontal and undisturbed; while in Russia, where they cover wide areas, they resemble the Cambrian beds of the same regions, in being so little affected by the disturbing and indurating processes of time, that they are often still very recent-looking sediments. "The sands and clays are as soft and incoherent as the similar rocks of Tertiary age are in the South of England." (Howe.) Limestones are scarce in the Ordovician of Northern Europe, in very striking contrast with those found in America.

Ordovician rocks occur over wide areas in Northern and Eastern Asia, and are found in a narrow strip along the northern coast of Africa; but they are absent from the greater part of Southwestern Asia, and from practically all of Africa except the region north of the Sahara. They occur in various parts of Australasia, and in the extreme southern part of South America, though absent from the central and northern portions of the latter continent.

The vast beds of Ordovician limestone and dolomite which are found in the valley of the Mackenzie River and in Alaska, prove that when they were made, a warm ocean extended into the arctic regions. "The same Middle Ordovician reef corals that are found in Tennessee and New York occur also in Baffin Island, the Mackenzie River valley, and in Alaska, though they are less abundant in the far north. We may therefore assume that the temperature of the lands and the seas in the Northern Hemisphere was nearly everywhere the same, and that it was warm temperate throughout." (Schuchert.)

Life

General Remarks. The life displayed in the Ordovician rocks is much more varied and luxuriant than the life of the Cambrian, and it is also, in general, of a higher grade. Or rather, we should say that *because* certain rocks show fossils with these characteristics, *therefore* they are classed as Ordovician. "All the great types of marine invertebrates, and most of their important subdivisions" (Scott), are exhibited in these rocks. The graptolites, the Cystoidea, the straight-shelled

FIG. 226. Galena dolomite, in the valley of Apple River, near Millville, Illinois. The lowest beds exposed contain *Receptaculites*, a kind of sponge regarded as characteristic of the Ordovician. (Shaw, U. S. G. S.)

cephalopods, and the trilobites are more abundant and more highly developed in the Ordovician strata than in any others.

It is the first grand display of the ocean life which we meet with in the fossiliferous series; but at the most, it is only a partial display of the *total* marine life which may have existed contemporaneously, the fossils of which geologists may have assigned to the Jurassic, the Cretaceous, or the Tertiary system. What glimmer of a scientific reason is there for saying that these Ordovician forms of life occupied the oceans exclusively, and

FIG. 227. View of Williams Cañon, Manitou, Colorado. The cañon walls are composed of Manitou limestone (L. Ordovician), with Sawatch sandstone (U. Cambrian) at base. The upper strata, above the cave entrance, are Carboniferous. (Stanton, U. S. G. S.)

that examples of the higher forms of life, such as the teleost fishes, or the ammonites and the nummulites, or even the mammals and other land animals, were not then in existence anywhere on earth? Any attempt to justify such an assertion must (1) assume the biological *onion-coat theory*, or (2) dogmatically deny the possibility of distinct *zoölogical zones and districts* in these early ages. In short, any such argument based on our ignorance or our denial of what may have existed elsewhere, is like the argument of a blind man based on what he can't see: it is not very scientific.

Kinds of Fossils. But we must record the actual kinds of fossils classed as Ordovician.

The *plants* are chiefly coralline algæ and other seaweeds; for although a few land plants have been reported from these rocks, and although the profusion of land plants in the other systems closely following this one makes the evolutionists think that the beginnings of such plant forms *ought* to be found in the Ordovician rocks, yet geologists have not generally credited the actual reports of such discoveries.

The remains of *Foraminifera* and *Radiolaria* have been

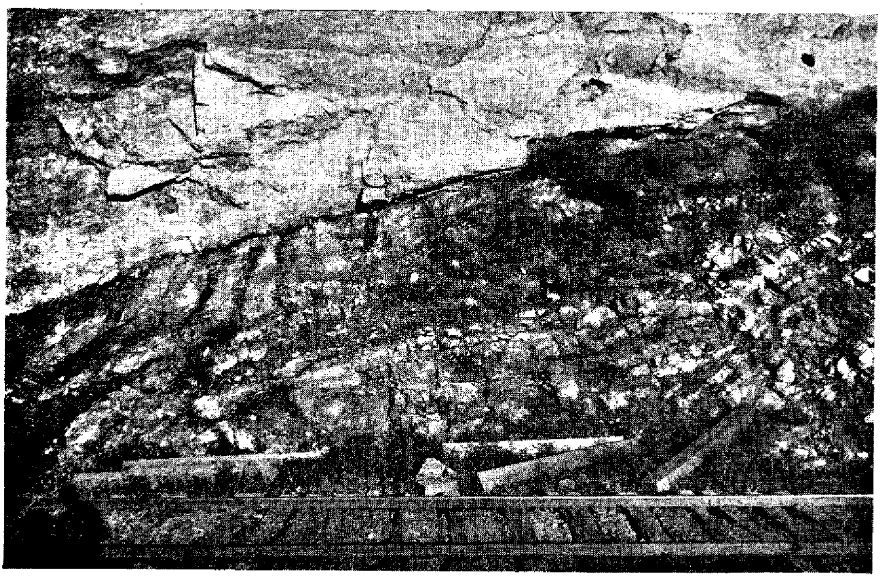

FIG. 228. Calciferous (M. Ordovician) beds resting on crystalline schists (Archæan), west of Downing Station, New York. (Darton, U. S. G. S.)

found in only a few localities, though in much abundance when they do occur.

Sponges with skeletons of calcium carbonate or of silica are common, though horny sponges, similar to the common bath sponge, occur here and there, but necessarily are not well preserved.

Graptolites occur in great profusion and in a great variety of forms. "So abundant are the graptolites that in many parts of the system they are almost the only fossils, and are employed to divide the substages into zones. Graptolite zones, with the same or closely similar species, and in the same order of succession, are found in Great Britain, the St. Lawrence and Champlain valleys, and in Australia." (Scott.)

Among the *corals*, there are many solitary cup corals, with many reef-building varieties, though, like the other corals classed

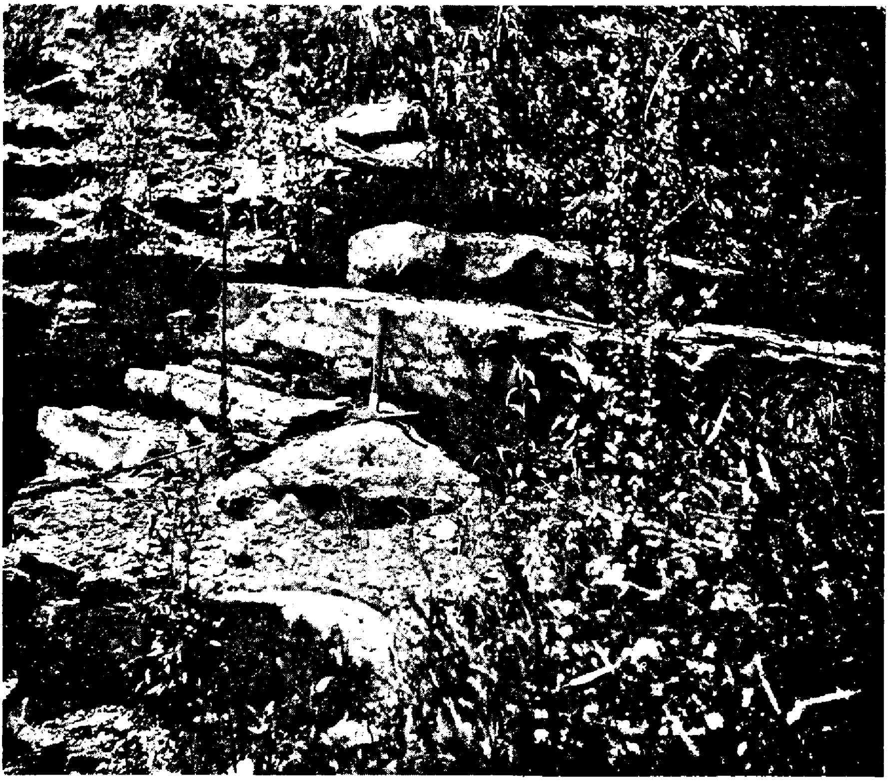

FIG. 229. Trenton limestone (U. Ordovician), near Lexington, Kentucky, one stratum, marked with the cross, containing heads of corals. (Photograph by Bassler.)

in the Paleozoic group, they show a marked bilateral symmetry, and have the septa arranged in multiples of four (*Tetracoralla*), instead of in multiples of six (*Hexacoralla*), as in the living species of corals.

Of the *Echinodermata*, cystoids are common, and so are the true crinoids; but they will be more fully described in the following chapter. Starfishes, brittle stars, and sea urchins occur, but are not very common.

Of the *Arthropoda*, the trilobites are more numerous and more highly developed in the Ordovician rocks than in any others; hence they are spoken of as "culminating" in this "period." Each subdivision of these rocks is labeled and ticketed with some particular variety of trilobite. The general characters of this class have been given in the preceding chapter. Another group of crustaceans, the *Eurypterida*, is also represented; and even an insect is reported from the Ordovician rocks of Scandinavia.

Fig. 280. Fault and dike on East Canada Creek, New York. Upper Ordovician limestones and shales have been faulted against Middle Ordovician sandstone, with conspicuous drag on the downthrow side of the fault. (Darton, U. S. G. S.)

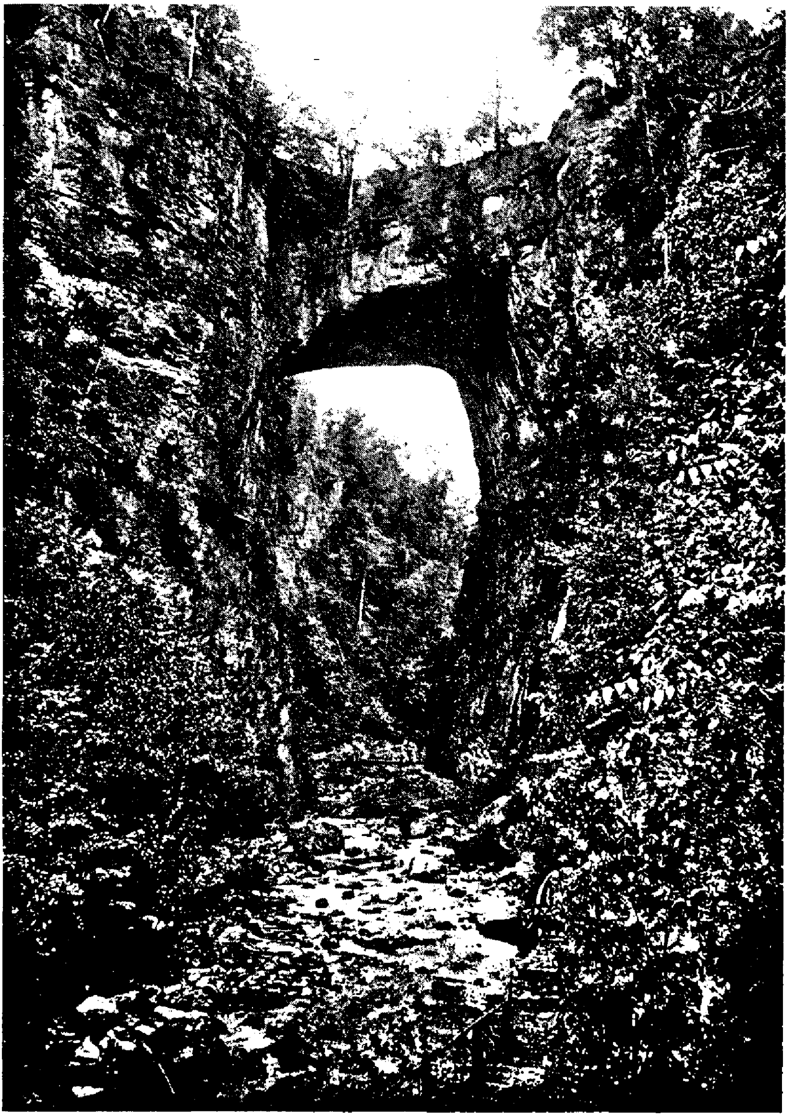

FIG. 231. Natural Bridge, Virginia. Probably a remnant of a former cave roof. The names of George Washington and many other notable persons are carved on the sides of the rocks, which are Ordovician limestone. (After D. W. Johnson.)

The *Brachiopoda* are second only to the trilobites as the characteristic animals of these rocks. They have been already described in the preceding chapter.

The *Mollusca* occur in great numbers, and all the leading divisions of this great phylum are represented. The cephalopods were all *nautiloids,* with chambered shells, like the living

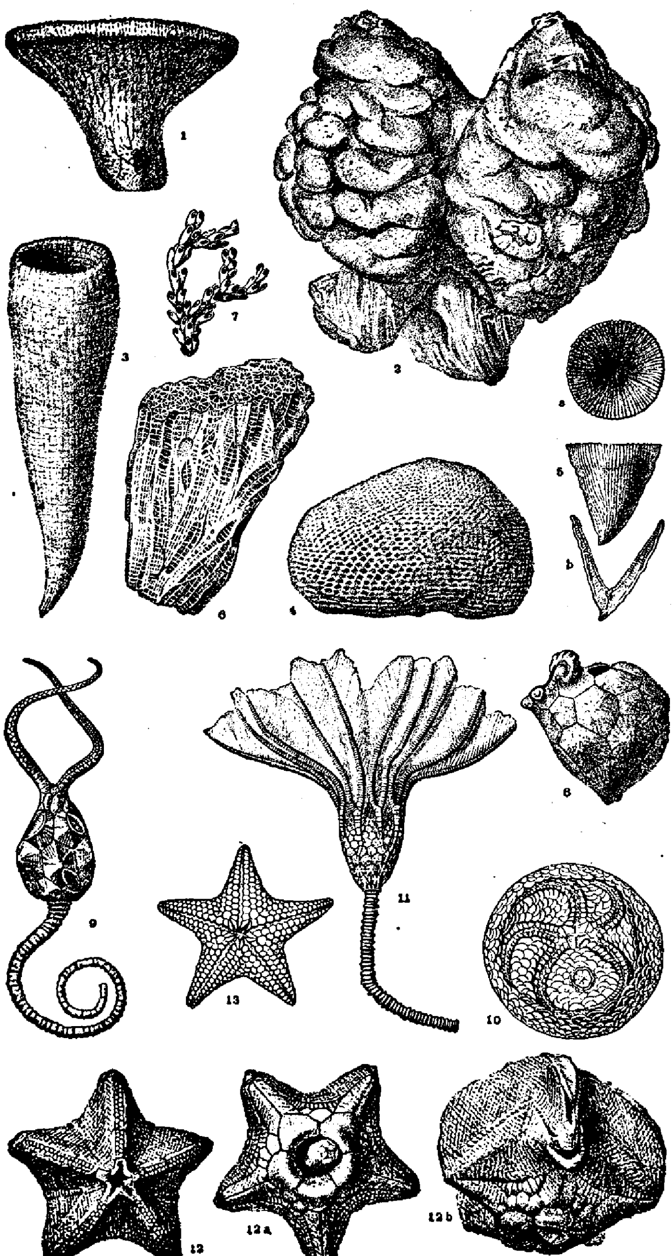

FIG. 232. ORDOVICIAN SPONGES, CORALS, ETC.

1, *Zittelella typicalis*, Ulrich and Everett, × ½, Trenton. 2, *Strobilospongia tuberosa*, Beecher, × ½, Trenton. 3, *Cyathophycus reticulatus*, Walc., × ½, Utica. 4, *Receptaculites fungosus*, Hall, × ½, Trenton. 5, *Petraia profunda*, Conrad, × ½, Trenton. 5a, *The same*, top view. 5b, *The same*, vertical section. 6, *Columnaria stellata*, Hall, × ½, Trenton. 7, *Romingeria trentonensis*, Weller, × ½, Trenton. 8, *Malocystites emmonsi*, Hudson, × 2, Chazy. 9, *Pleurocystites filitextus*, Bill., × 1, Trenton. 10, *Lepidodiscus cincinnatiensis*, Hall, × ½, Richmond. 11, *Glyptocrinus dyeri*, Meek, × ½, Richmond. 12, *Blastoidocrinus carchariædens*, Bill., × ¾, Chazy. 12a, *The same*, basal view. 12b, *The same*, side view. 13, *Palæasterina stellata*, Bill., × ½, Trenton. (After W. B. Scott, "Introduction to Geology," permission of Macmillan Co.)

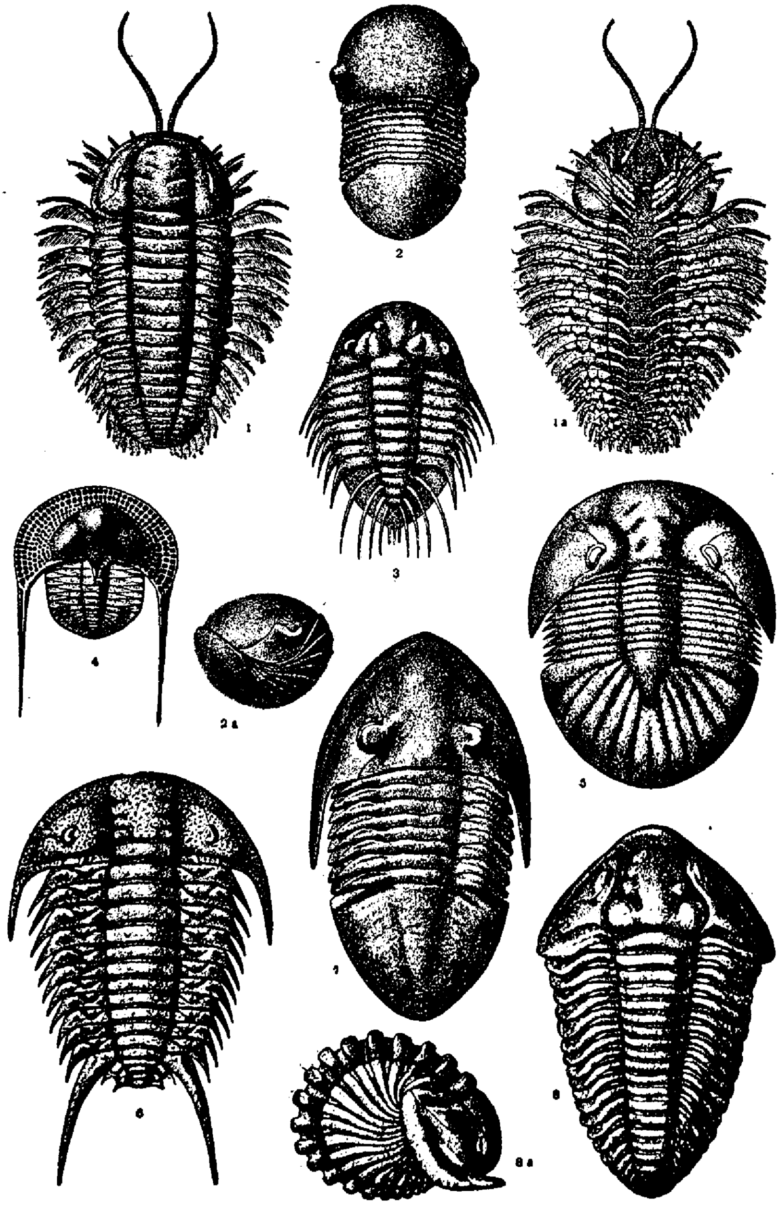

Fig. 233. ORDOVICIAN TRILOBITES

1, 1a, *Triarthrus becki*, Green, × 3/2, Utica. Restoration by Beecher of dorsal and ventral sides. 2, *Bumastus trentonensis*, Emmons, × ½, Trenton. 2a, *The same*, from the side, rolled up. 3, *Acidaspis crosotus*, Locke, × 4, Richmond. 4, *Trinucleus concentricus*, Eaton, × 1, Trenton. 5, *Bronteus lunatus*, Bill., × 1, Trenton. 6, *Ceraurus pleurexanthmus*, Green, × 1, Trenton. 7, *Isotelus maximus*, Locke, × 1, Trenton. 8, *Calymmene callicephala*, Green, × 1, Richmond. 8a, *The same*, rolled up, from the side. (After W. B. Scott, "Introduction to Geology," permission of Macmillan Co.)

pearly nautilus. The huge straight shells of some of these creatures are very common, and some of these shells are 10 feet long. One genus of this group, *Endoceras,* is found in no other rocks except the Ordovician. It is thus a very excellent "index fossil."

Economic Products

Many marine sediments contain so much organic material disseminated through them that when it becomes transformed, by loss of oxygen, into the various *hydrocarbons* (oils), it may become concentrated into limited areas underground, and stored in reservoirs or pools. Black shales often contain oil as high as 20 per cent of their mass; and in that case, they will burn almost like coal. Even when the oil content of a shale is not more than 5 per cent, it would be commercially worth extracting, if the cost of such extraction were not too great. But nature has often performed this extraction of the oils on a gigantic scale, the percolating waters having carried the oil with them and accumulated it under heavy pressure in porous sandstones or conglomerates, where the oil may be found in a vast sheet lying on the top of the water, with some impervious layer of rock situated above it, like a shale or a clay bed, which keeps the oil (and its associated gases) from rising to a higher level and perhaps escaping into the air.

These hydrocarbons are thought to have resulted chiefly through bacterial agency, from the decomposition of animal material originally disseminated through some of the rocks. Optical examination of these mineral oils proves them to be of animal origin, since they have the same optical properties as animal oils.

"Oil and gas are usually found in the flattened tops of depressed geologic arches and down the slopes of anticlines where the dip of the strata is arrested so as to form shelves or terraces (the 'terrace structure' of oil experts), but there is always above the productive zones an impervious and usually a thick shale cover. Broadly stated, the thicker the shale formation, the more impervious the cover, and the deeper the storage bed, the richer the gas or oil field."— *Schuchert.*

In some instances, marine invertebrates, or even microscopic organisms, may have contributed largely to produce the organic materials from which these oil deposits have been derived. More often, however, it seems to have been *fish,* or even *mammalian* remains. At Lompoc, California, and in many similar formations, the petroleum in the rocks very evidently came from the millions of fish there entombed; while at Hollywood,

near Los Angeles, it is equally evident that the immense quantities of mammalian remains in the strata are perhaps the chief source of the organic materials forming the oils. In the latter

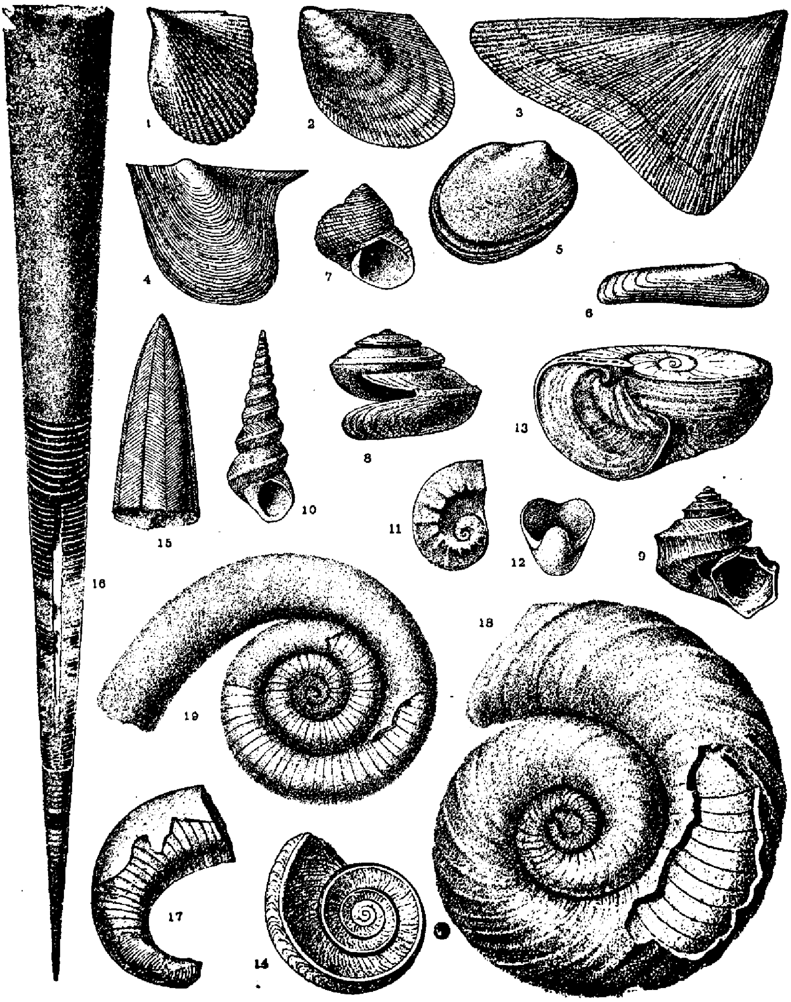

FIG. 234. ORDOVICIAN MOLLUSCA

1, *Byssonychia radiata*, Hall, × ½, left valve, Trenton. 2, *Ambonychia planistriata*, Hall, × ½, left valve. 3, *Opisthoptera fissicosta*, Meek, × ½, right valve, Richmond. 4, *Pterinea demissa*, Conrad, × ½, left valve, Trenton. 5, *Cyrtodonta huronensis*, Bill., × ½, right valve, Lowville. 6, *Cymatonota attenuata*, Ulrich, × ½, right valve, Richmond. 7, *Cyclonema humerosum*, Ulrich, × ½, Lorraine. 8, *Eotomaria supracingulata*, Bill., × ½. 9, *Trochonema umbilicatum*, Hall, × ½, Trenton. 10, *Hormotoma gracilis*, Hall, × ½, Trenton. 11, *Cyrtolites ornatus*, Conrad, × ½, Lorraine. 12, *Protowarthia cancellata*, Hall, × ½, Black River. 13, *Maclurea logani*, Salter, × ½, Trenton. 14, *Ophileta compacta*, Salter, × ½, Beekmantown. 15, *Conularia trentonensis*, Hall, × ½, Trenton. 16, *Orthoceras multicameratum*, Hall, × ⅛, Lowville. 17, *Cyrtoceras juvenalis*, Bill., × ½, Trenton. 18, *Eurystomites occidentalis*, Hall, × ¼. 19, *Schrœderoceras eatoni*, Whitfield, × ½. (After W. B. Scott, "Introduction to Geology," permission of Macmillan Co.)

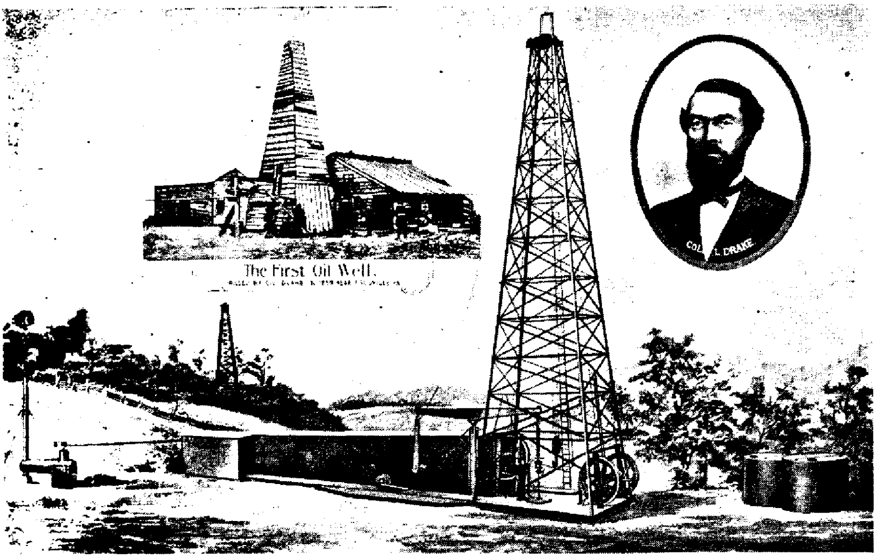

FIG. 235. The old and the new.

place, the mammals were evidently piled together in the strata like driftwood, the ordinary processes of decay having been arrested in a few spots, called the *La Brea tar pits.* But it is quite clear that these beds were once just as completely packed with mammalian remains over acres or even over many square miles, as we find in the case of the beds at these tar pits. In many other localities, we do not, it is true, find the peculiar combination of circumstances which we find here, with great numbers of bones preserved, as it were, in their own fat; but there is little doubt that in many other localities, mammalian remains have contributed largely to the production of the hydrocarbons.

Throughout Ohio and Indiana, the oil and gas are found stored in the upper 20 to 30 feet of the porous Trenton dolomite (Middle Ordovician), from 1,000 to 2,000 feet below the surface. The dark Utica shales form the impervious cover in this instance; and below the gas and oil, there is always "highly saline water."

Gas wells were first put down at Findlay, Ohio, in 1862; but oil had been struck in drilled wells several years before this in Pennsylvania (1859). The oils which have been brought to the surface in the United States since that time have been estimated at 2,500,000,000 dollars. Though at first discovered in definite horizons of rock, and thought to be confined to these geological formations, yet, like the coal deposits of the world, the oil has since been found in practically every one of the other "later" formations.

FIG. 236. Polished slab of dark red Tennessee marble, with sections of cephalopod shells. (Dale, U. S. G. S.)

The Ordovician marbles of Vermont, and the beautiful red limestones or marbles of Tennessee, are much used for building and decorative purposes. Portland cement is also extensively made from Ordovician and other limestones. Lead and zinc ores are mined in Iowa, Wisconsin, and Illinois, from Middle Ordovician dolomites, a Trenton limestone-dolomite known as the Galena formation. Large quantities of calcium phosphate, useful as a fertilizer, are obtained from the limestones of Central Tennessee, formed from minute gastropod shells, as already described.

CHAPTER XXIV

Fossil Radiates

Bilateral and Radial Symmetry. Most of the animals with which we are familiar are constructed on a plan of what is termed *bilateral symmetry;* that is, they are so constructed that a line may be drawn through them in such a way as to divide the body into two equal and symmetrical parts, each structure in one part having its duplicate in a similar structure in the other part.

However, there are many animals which do not have any bilateral symmetry, but which seem to be constructed on a plan of more or less *radial symmetry* instead. In the early days of natural science, a group of animals was named *Radiata;* but the naturalists of recent years have discarded this term, because they say that not all the animals thus described have really originated from a common source — so much has the prevailing doctrine of evolution dominated every department of modern scientific work. For the study of the embryology of the seemingly radiate animals reveals the surprising fact that many of them *start out in their early days with a decidedly bilateral symmetry,* and only later do they change over into animals of radiate symmetry. Yet, in spite of all these protests of the modern evolutionists, this combining of many different kinds of animals into a group which might be called *radiate animals,* is a very convenient one, and very well answers our purpose in this present chapter.

These animals may be divided into two quite distinct divisions, the *Cœlenterata* and the *Echinodermata.* The former division includes the jellyfishes, the sea anemones, and the corals; while the latter includes the starfishes, the sea urchins, and the crinoids. Practically all of both divisions live only in salt water.

The name *Cœlenterata* means that these animals have but one internal or body cavity, which serves both as a *cœlom* (or body cavity) and as an *enteron* (or digestive cavity). In contrast with these, all the higher animals have a body cavity, and also, inside this body cavity, another cavity, which serves for digestion, and which is called the alimentary canal. However, while most of the cœlenterates are simple in their organic structure, many of them are extremely elaborate in their appearance. "In their variety they seem nearly to exhaust the possibilities of radial symmetry, and many are very flowerlike. They have,

therefore, also been called zoöphytes (plant-animals), and their budded colonies afford interesting illustrations of coöperation and division of labor." (Schuchert.)

The *Echinodermata,* while having in the mature stage a radial symmetry just as pronounced as the ones already mentioned, have also a true body cavity in addition to the digestive tract; and on this account, modern scientists refuse to place them with the Cœlenterata under the old term *Radiata.* But in the larval stage, the echinoderms have a *true bilateral symmetry;* and on this account also, they are placed in another phylum by themselves. As a rule, they do not have as pronounced a calcareous skeleton as some of the cœlenterates, especially as the corals; and for this reason, they do not as largely contribute toward rock making.

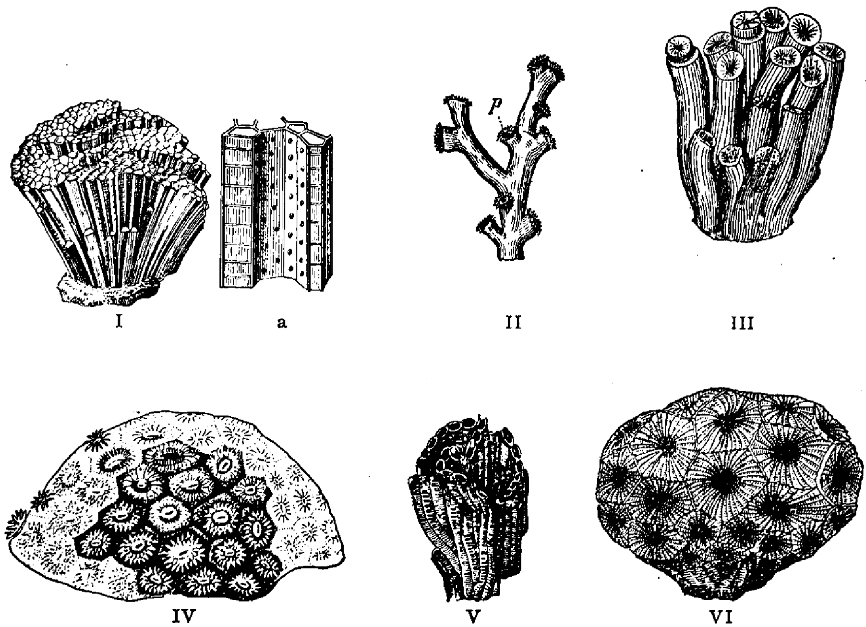

FIG. 237. Some representative fossil corals. I, *Favosites polymorpha,* Devonian; *a,* corallites, enlarged, two being broken open and showing the tabulæ. II, a modern branching coral; *p,* an active polyp. III, fossil cup coral, *Cyathophyllum cæspitosum,* Devonian. IV, a living massive coral, called a star coral. V, a fossil coral, *Halysites catenularia,* Silurian. VI, a fossil coral, *Cyathophyllum hexagonum,* Devonian. (From "The New International Encyclopædia," by permission.)

This astonishing change from a marked bilateral symmetry in the larval stage to a radial symmetry in the adult form, "constitutes one of the most remarkable life-histories known in the animal kingdom." ("Cambridge Natural History," Vol. 1, p. 429.)

Classification. These two groups of radiate animals may be briefly set forth in the following table:

Phylum Cœlenterata. Chiefly marine. Free or attached. Some live singly as independent individuals, others only as members of a colony. They have skeletons composed of calcium carbonate or of horn.

Class *Hydrozoa* (Hydroids). The modern kinds are very simple in construction, and are quite unimportant geologically. But the graptolites, which were ancient hydrozoans with horny skeletons, are found in many of the Paleozoic rocks.

Class *Anthozoa.* These are coral polyps.

Sea Anemones. These live as individuals, not in colonies, and do not secrete any hard skeleton.

Stony Corals. These secrete a hard external skeleton composed of calcium carbonate. They are subdivided into the *Tabulata,* the *Tetracoralla,* and the *Hexacoralla,* the last named being similar to most of the living corals.

Phylum Echinodermata. Chiefly having an external skeleton of calcium carbonate composed of several pieces.

Class *Stelleroidea.* The starfishes. Free individuals.

Class *Echinoidea.* Sea urchins. Free individuals.

Class *Crinoidea.* Feather stars or sea lilies. Mostly attached.

Class *Blastoidea.* Pentremites, or "fossil hickory nuts."

Coral Polyps and Their Kin

General Characters. The members of this phylum are usually provided with an apparatus for stinging other animals. This stinging is done by means of a sharp, needlelike arrangement which is shot forth from a cell which is itself embedded in the tissues of the animal. A given surface may have a great number of these *stinging cells.* This sting is set off by a very delicate sensory arrangement around its base, and it carries a poisonous fluid. The great numbers of these stinging cells possessed by the animal thus serve as a defense, or as a means of paralyzing other minute animals which may then be used as food.

These animals are little more than an animated sac, the closed end of which is attached to some object, as a reef or the bottom of the sea, while the free end is open and contains the mouth. Some of them are minute, others are one or more inches in size.

The *medusæ,* or jellyfishes, belong to this group, and are of very much the same construction as the sea anemones and the coral polyps; but as they do not have any hard parts, they

are seldom found as fossils. Impressions referred to medusæ have been found in the Cambrian, Liassic, and Cretaceous beds.

The Graptolites. The *graptolites* (from a Greek word meaning *to write,* in allusion to the fossil traces which look somewhat like pen markings) were hydroid animals arranged in a line or a series, with occasional thin tubular buds composed of horny matter. They were arranged singly in a series, or in sets of two or four. Numbers of such colonies were fastened to a central piece which resembled a saucer upside down, the colonies resembling the rays of a star, and the whole thing being able to float around in the water. Others of the graptolites were attached to the sea bottom or to a piece of seaweed, and in structure they resembled a sprig of a plant. These colonies were mostly fan-shaped or funnel-shaped. Graptolites are generally *black* when found as fossils, and frequently occur in black shales. The graptolites are almost entirely restricted to the Ordovician and Silurian rocks, and are regarded as excellent "index fossils."

The Anthozoa. The term *Anthozoa* is made to include the sea anemones and the corals. The animals themselves are called *polyps.* They are of rather complicated internal structure, and usually secrete a hard part or skeleton called the *corallum,* composed of calcium carbonate, this being secreted by a portion of the outside of the creature, and being attached to some fixed object, either to another similar corallum or to a rock. As the soft part of the polyp has a radiate internal structure, or one divided off by radial partitions, and as the hard corallum takes on the exact form of the internal structure, we have an exact pattern of the polyp preserved in the rock. It is these limestone skeletons fastened together as colonies which we find as fossils. As the sea anemones have no skeleton, they are not preserved as fossils. Some corals secrete a black skeleton of horny material, and are accordingly called "black coral." Sea anemones are sometimes over six inches across; but the coral polyps are commonly not more than a quarter of an inch in size, though the groups of skeletons when combined into a colony may sometimes be 10 or 15 feet across.

Cup Corals. The stony cuplike coralla of single polyps, and known as *cup corals,* are very common in all of the Paleozoic rocks. They did not form colonies, because they did not multiply by budding, but by sexual reproduction. These cup corals are usually rudely cone-shaped, and internally have many partitions, or septa, arranged radially from the center to the outer

wall. One kind of cup coral, called the *Archæocyathidæ,* formed cups less than three inches in length, and are restricted to the Lower Cambrian.

Colonial Corals. The *Tabulata* were colonial corals, the individual corals being small crosswise; but as they built long tubelike structures which were partitioned off transversely by many *tabulæ* (meaning *bottoms*), they were quite important as coral makers. There are no radial septa. The tabulate corals are found principally in the Silurian and Devonian systems.

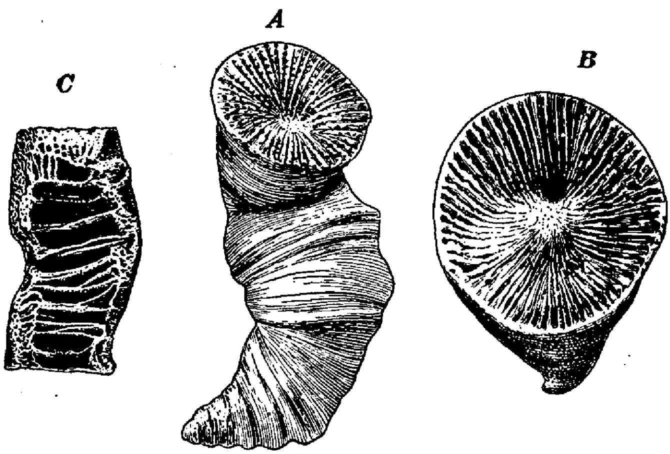

FIG. 238. Paleozoic cup corals (*Tetracoralla*). A, common Devonian form (*Heliophyllum halli*), with ornate septa. *B*, Silurian form (*Zaphrentis umbonata*), with deep cup, many septa, and a fossula. *C*, Devonian species (*Amplexus yandelli*) sectioned to show tabulæ. (After Schuchert and Rominger.)

Halysites, a chain coral, abounds in the Silurian and the Ordovician; while *Favosites,* a honeycomb coral, is very abundant in the Silurian and the Devonian. Immense limestone rocks of wide extent are largely formed of their remains.

The corals with septa in four groups, or the Tetracoralla, are other forms found in the Silurian and the Devonian, and less commonly in the "later" systems of the Paleozoic. They are supposed to be found in none of the "subsequent" formations, and are classed as "extinct." However, it is not always easy to distinguish those with four sets of septa from those with six, the latter being the living corals, and found as fossils extensively in the Mesozoic and the Tertiary.

The *Hexacoralla,* or corals with six sets of septa, are the modern reef builders of the tropical waters, and various genera of them are found as fossils in the Mesozoic and Tertiary rocks.

The six primary septa are more easily distinguished in the young polyps, but are preserved as more or less distinguishable in maturity. The *staghorn corals* and the *brain corals* belong to this division.

Habitat. As the ancient corals were probably similar to the modern kinds in habits and requirements, it will be interesting to study briefly the ways in which the modern species live. Modern Hexacoralla are found in the very deep waters, even down as far as 11,000 feet, where the waters are icy cold; but they are mostly confined to the warm waters within 240 feet of the surface. It is chiefly the solitary corals which are found in the deep waters; the reef makers live almost exclusively near the surface, where there is plenty of sunlight and a warm or tepid water. Indeed, the greater number of species are found in water less than 150 feet deep. In this zone, the water is of a temperature between 68° and 78° F., though they will stand to have the water some ten degrees warmer than this, but not colder. Between 600 and 2,400 feet is another zone of single corals, or of delicate branching colonies; and here the water ranges between 40° and 50° F. Most of the fossil corals that are similar to living forms are like the warmth-loving reef builders, and must have lived in warm waters in the olden time, though their remains are often found in the far north and even in the arctic regions. But when the arctic regions were warm, the deep waters of the ocean were probably much warmer than at present; and in that case, the reef-building corals may have lived at greater depths than they do at present.

Echinodermata (Spiny-Skinned Animals)

Structure. These animals have a radiate structure with the parts generally arranged in fives, a characteristic best seen in the starfishes. In other members of this group, this pentameral arrangement is always present, but is sometimes obscured by other peculiarities. Usually there is also a set of spines composed of calcium carbonate embedded in the dermis; or there is a strong set of plates inclosing the softer parts of the animal.

Two or more rows of soft, tubelike processes called *tube feet* extend along the radii, or arms. These tube feet constitute the chief locomotive organs of the animal, and terminate in sucking disks. The tube feet are connected with a very elaborate system of internal tubes, which are not found in any others of the animal kingdom, this internal tube system forming what is called the *water-vascular system.* A circular canal around the centrally situated mouth unites all these internal tubes; and the

sea water has access to this canal and to the tube feet through a large porous plate on the dorsal side, the amount of water in the tube feet being under the control of the animal.

Subdivisions. The *Echinodermata* are divisible into two main groups based on the habits of the animals. The *starfishes* and the *echinids* are free; while the *crinoids* and the *blastids* are sedentary or attached, with long stalks like those of a flower, by means of which they are anchored to the bottom or to some fixed object. In the free forms, the mouth is on the ventral or under side of the body, thus facing downward to the ground over which the animal crawls in search of its food. The stalked forms, however, have all this reversed, the mouth and the ventral surface being upturned, like a flower, the stalk being fastened to the under or dorsal side. The free or active forms feed on mollusks and other large animals; while the stalked forms feed on the minute or microscopic life that comes to them in the passing waters. Most of the stalked kinds live at considerable depths in the ocean. Many of the echinoderms, particularly the starfishes, have extraordinary powers of regeneration, or of growing new parts that have been lost or broken off. Any part of a starfish which retains a portion of the central disk may eventually grow into an entire animal.

The Starfishes. *Starfishes* are found in the Ordovician, but are not common in the Paleozoic rocks. A few entire ones are found in some of the Mesozoic strata; but as a rule, entire specimens are rare, and they are not considered of much importance for identifying different formations. Doubtless their broken skeletons contributed somewhat to the formation of the materials of which the limestones were made.

The Echinids. A group called *echinids* is named to include the sea urchins, the heart urchins, and the sand dollars. They are very spiny creatures, in some of them the spines being movable on ball-and-socket joints. The heart urchins are not as regular in construction as the real sea urchins, but are more elongate, sometimes being distinctly heart-shaped, whence the name. The sand dollars also are irregular in form.

The echinids are very rare in the Paleozoic rocks, but are common in the Mesozoic, and are much depended upon as "horizon markers," particularly in Europe, "where the Mesozoic strata are at times crowded with them." (Schuchert.) In Alabama, Texas, and Mexico, the Comanchean beds often contain them. The irregular kinds are regarded as good index fossils of the Jurassic and the Comanchean. Some 5,000 fossil species are known, while only a tenth as many are living.

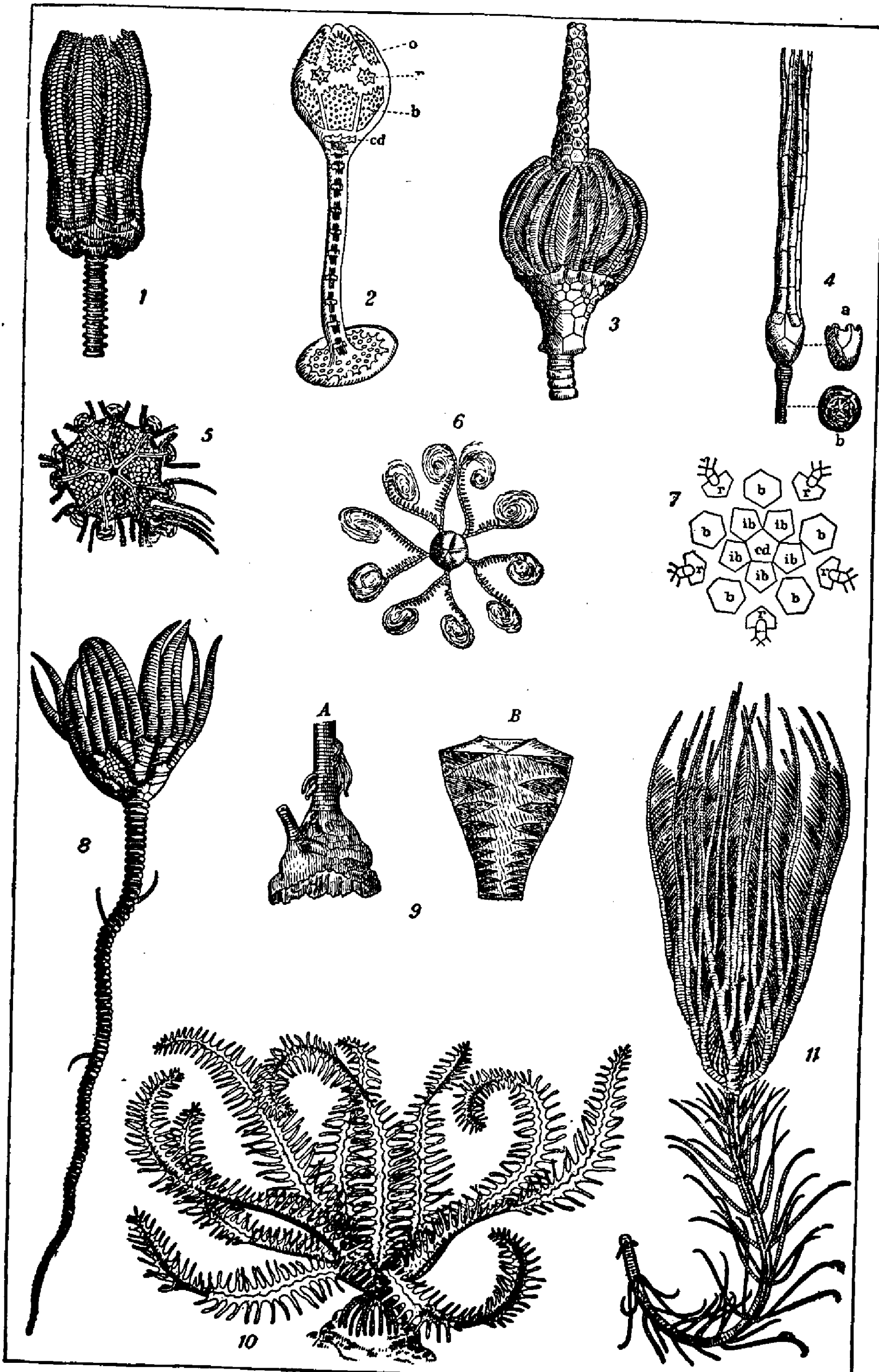

FIG. 239. CRINOIDS

The Crinoids. The *crinoids* are by far the most important of the fixed or sedentary echinoderms. The name means that they look *like lilies;* and they are often called *stone lilies,* or sometimes *feather stars.* While many of them are fixed to the bottom by a long stalk, some of them are free, while all are free in their younger stages of growth. They live in groups, or are gregarious in habit.

They consist of a *calyx,* the *arms,* and the *stalk.* The arms and the calyx are also included under the general word *crown,* which thus means all except the stalk. The latter is made up of many disklike perforated pieces placed in a column one above another, and composed of calcium carbonate. The stalks may be from 6 inches up to 18 inches; though one Jurassic species had a stalk 50 feet long, with a crown a yard in width as well as in length.

From the modern seas, 576 species of crinoids have been described, comprised in 142 genera and 28 families and sub-families. Only 76 species of these are *stalked,* the rest belonging to the unstalked or comatulid type. (A. H. Clark.)

As fossils, the crinoids are scarcely second to the corals in forming immense limestone deposits. A form called *box crinoids,* with a calyx that was large and boxlike, were very common. Many of the Mississippian limestones are formed of their remains. Crinoids are found in all the Paleozoic rocks. Kinds distinct from those of the Paleozoic occur in the Mesozoic, the latter being similar to the kinds alive to-day. Good whole crowns are never very common, for the reason that the pieces composing the skeleton were loosely embedded in the skin, and readily went to pieces when the animal died. But their broken stalks and crowns have accumulated into vast limestones many feet thick and extending for tens or even hundreds of miles.

There is "a bewildering variety" among the fossil crinoids, and "there is no agreement among experts as to how they should be classified." (MacBride.)

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1. An encrinite (*Encrinus*), fossil in the Triassic. 2. Larva of a feather star. (See 10 and 7.) 3. *Batocrinus pyriformis,* fossil in the Subcarboniferous of Iowa. 4. *Pisocrinus flagellifer,* fossil in the Silurian of Gottland; *a,* posterior view of a perfect calyx; *b,* calyx seen from one side. 5. Type of calyx with a coriaceous skin in which calcareous plates are embedded. 6. A free-swimming crinoid (*Saccocoma pectinata*), fossil in the Upper Jurassic lithographic slates of Bavaria. 7. Diagram of arrangement of principal pieces in the calyx of a crinoid: *b,* basals; *ib,* infrabasals; *r,* radials; *cd,* centrodorsal (compare 2, where the letters are the same, plus *o,* orals). 8. *Woodocrinus macrodactylus* from the Carboniferous of Yorkshire, England. 9. Apiocrinus: *B,* longitudinal section through the uppermost stem joints of *Apiocrinus parkinsoni* (Oölitic), showing empty spaces between them; *A,* restoration of the base of another species (*Apiocrinus roissyanus,* U. Jurassic). 10. A feather star (*Antedon rosacea*), now living on European coasts; 2 is the larva of this, showing developing plates (see 7) of the calyx. 11. An existing deep-sea "stone lily" (*Metacrinus interruptus*). (From "The New International Encyclopædia," by permission.)

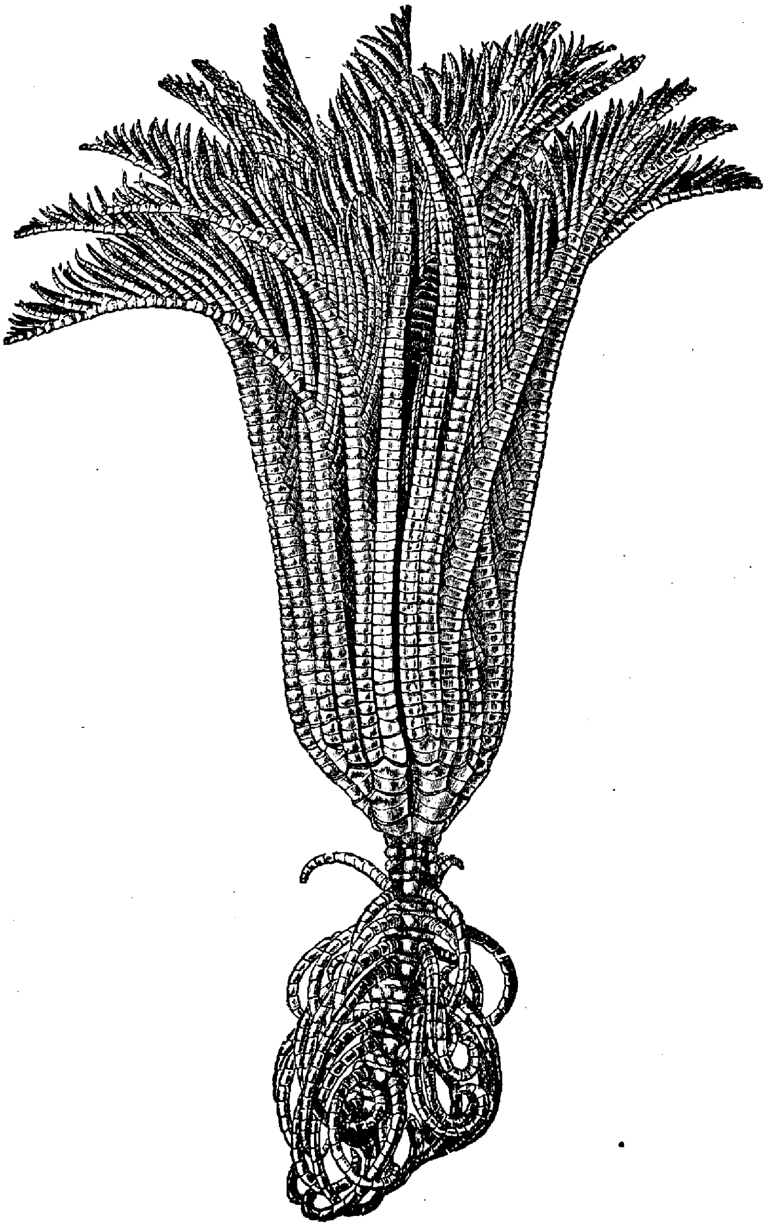


FIG. 240. Fossil crinoid (*Pentacrinus*) found in Jurassic rocks. (After Kirk.)

"The discoveries of the last few years have shown that the living crinoids, far from being rare or few in numbers, are abundant both as individuals and as species, and that in all localities where the somewhat exacting conditions under which they can exist are met, they occur, sometimes in enormous numbers. The requirements necessary for the mainte-

nance of crinoidal life are unfortunately of such a nature that, though quite generally distributed in the deeper waters of the oceans, they become rare or very local in the littoral, which, together with the great difficulty of preserving them in anything approaching satisfactory form, has served to keep them enshrouded in mystery while animals of other types engaged the attention of investigators."—*Austin H. Clark, "Sea Lilies and Feather Stars," Smithsonian Institution, Miscellaneous Collection, Vol. 72, No. 7, p. 2.*

The stalked genera are confined to considerable depths in the ocean, "and can only be obtained by deep dredging." (MacBride.) Hence it seems reasonable to conclude that *the ancient kinds also lived in the deeper waters generally or exclusively.* The fact that crinoidal limestones so frequently occur alternating with shales or sandstones, or even alternating directly with the coal beds themselves, has been taken as evidence that the ancient crinoids may have lived in shallow water. But it would be much more legitimate to argue that these conditions are proof that very abnormal circumstances prevailed when these rocks were laid down.

The Blastoids. The *blastoids,* or pentremites, are fossils resembling nuts in form, and are very common in the Mississippian beds of the Southern States, where they are called "fossil hickory nuts." They are used as "guide fossils" for the strata wherein they occur. They resemble the crinoids except that they were compact and had no arms. The calyx is usually made up of 13 plates. They seem to be wholly extinct.

Difficulties. The following remarks, while referring primarily to the Asteroidea, are of value as throwing light on the classification of many other groups of animals as well:

"Whilst there is considerable agreement amongst authorities as to the number of *families,* or minor divisions of unequivocal relationship, to be found in the class Asteroidea, there has been great uncertainty both as to the number and limits of the *orders* into which the class should be divided, and also as to the limits of the various *species.*

"The difficulty about the species is by no means confined to the group Echinodermata; in all cases where the attempt is made to determine species by an examination of a few specimens of unknown age there is bound to be uncertainty; the more so, as it becomes increasingly evident that there is no sharp line to be drawn between local varieties and species. . . .

"The disputes, however, as to the number of orders included in the Asteroidea proceed from a different cause. The attempt to construct detailed phylogenies [pedigrees of evolutionary descent] involves the assumption that one set of structures, which we take as the mark of the class, has remained constant, whilst others which are regarded as adoptive, may have developed twice or thrice. As the two sets of structures are of about equal importance, it will be seen to what an enormous extent the personal equation enters in the determination of these questions."—*"Cambridge Natural History," Vol. 1, pp. 459, 460.*

CHAPTER XXV

The Silurian System

Extent and Subdivisions. If we take the world over, the Silurian system is not as widespread or as important as is the Ordovician system. In extensive areas where the latter is well developed, the Silurian is either wholly absent or is but scantily represented, though there are some additional localities where we find Silurian rocks far from any similar outcrop of the Ordovician beds. The name *Silurian* was given by Murchison, as the result of his study of the rocks in Southwestern Britain, being based on the name *Silures,* that of an ancient tribe who used to inhabit Wales.

The following classification includes some of the chief formations grouped under the Silurian system:

Upper Silurian or Monroan	Manlius limestone Rondout water lime Cobleskill and Akron limestones Camillus shale (in part)
Middle Silurian or Salina	Camillus shale and gypsum (in part) Syracuse salt series
Lower Silurian or Niagara	Upper Niagara (including Guelph dolomite, and Lockport dolomite and limestone) Middle Niagara (including Rochester shale, and Clinton limestones and shales) Lower Niagara or Medina (including Oneida conglomerate, Medina sandstones and shales, and Whirlpool sandstone)

In Europe, the Silurian is made to include the *Ludlow* (also called the *Clunian* on the Continent) and the *Wenlock.*

Lithic Characters. The *Clinton shales,* which change into limestones as they extend westward, run from New York State to Indiana, perhaps also through Illinois to Missouri. These beds extend southward to Alabama; while the same beds (doubtless with extensive interruptions between) have been observed in Nova Scotia and Wisconsin. Extensive stratified beds of red iron ore (hematite) occur in the Clinton formation in the two localities last mentioned, and also in the State of New York.

The limestones of the *Niagara series* (*Lockport-Guelph*) are among the most extensive limestones in America. They

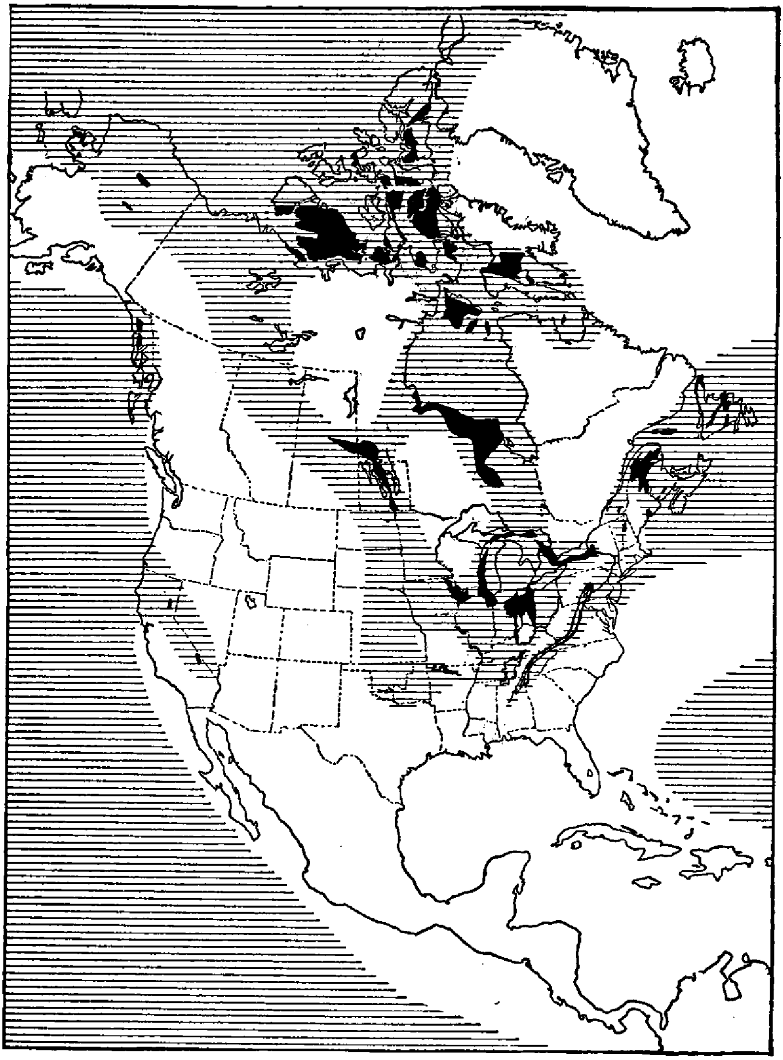


FIG. 241. Map showing Silurian outcrops in North America, which are in black. Silurian strata are not known over the white areas. (After W. B. Scott.)

extend (with interruptions) from the Great Lake district to Wisconsin, across Illinois, and thence to Iowa, Missouri, and Western Tennessee, a distance of nearly 1,000 miles. Similar rocks occur in the Maritime Provinces of Eastern Canada, also in Manitoba and south of Hudson Bay, and on many of the islands in the arctic regions. The limestones of the Niagara contain many corals and crinoids, indicating that these beds were formed in clear water, some of them probably in compara-

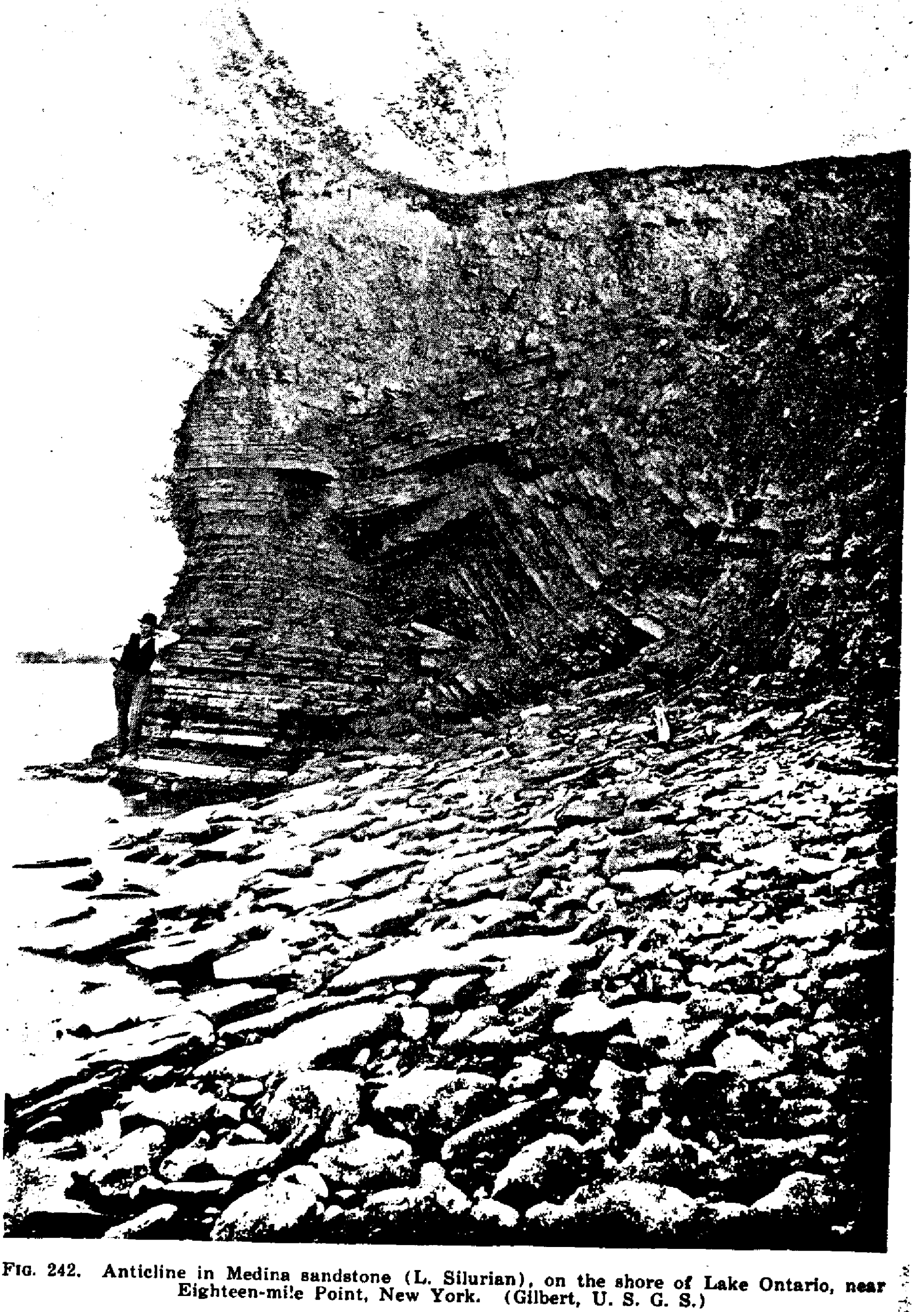


FIG. 242. Anticline in Medina sandstone (L. Silurian), on the shore of Lake Ontario, near Eighteen-mile Point, New York. (Gilbert, U. S. G. S.)

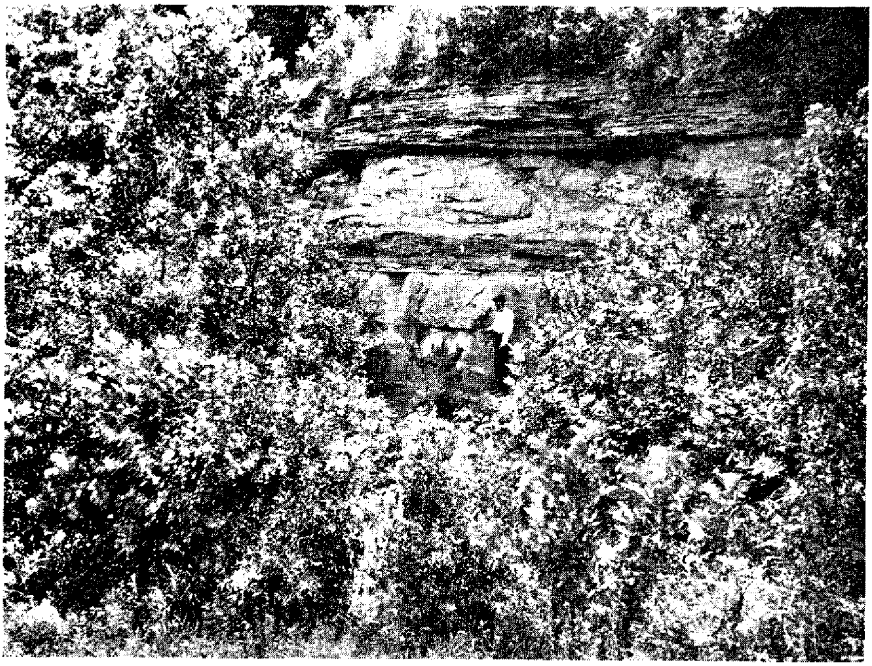


FIG. 243. Louisville limestone (L. Silurian), in a bluff of the Ohio River, about one mile northeast of Louisville, Kentucky. (Butts, U. S. G. S.)

tively deep water. At Niagara Falls, the Silurian limestone is much harder than the underlying shales; and as the latter are gradually worn away by the spray of the falls, the overlying limestone breaks off, causing the falls slowly to move upstream, as has already been explained.

FIG. 244. Niagara Falls

Distribution. This Silurian limestone underlies the city of Chicago, and much of it is quite saturated with oil. It is here called "Athens marble" or "Joliet" building stone. Corals are very plentiful and conspicuous in the limestones of Wisconsin, with many crinoids also; while similarly abundant corals are observed at Louisville, Kentucky, though these are classed as Lower Silurian.

On Anticosti Island, in the Gulf of St. Lawrence, is found

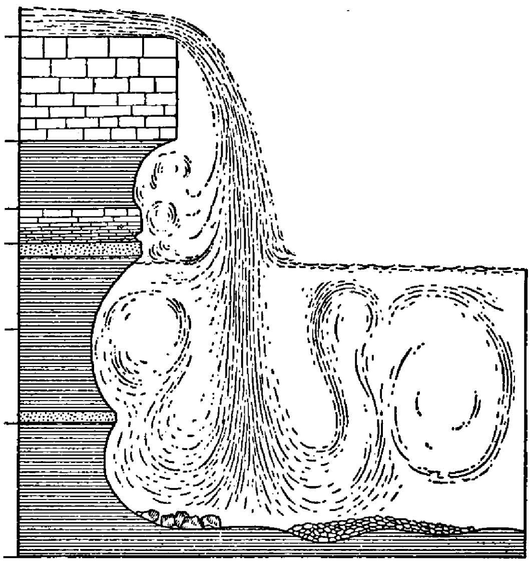


FIG. 245. Sectional diagram through the Horseshoe Falls, Niagara, showing the sequence of the formations and the depth of the water below the falls. Height of falls, 158 feet; depth of water, 150-200 feet. (After G. K. Gilbert, U. S. G. S.)

what is regarded as one of the most complete sets of the Silurian beds in North America.

In Europe, there is the same twofold division in the Silurian rocks which we found in the Ordovician of that continent. They occur in Ireland, Wales, Northern England, and in Scotland. They occur also in Scandinavia and in Russia, one of the typical examples of these rocks being found on the island of Gottland, off the coast of Sweden. Silurian coral rocks are plentiful in Siberia, and they contain the same kinds of corals as are found in the arctic regions of North America, probably implying that these rocks extend, in many places, under the Arctic Ocean. A chain coral (*Halysites*) and a honeycomb coral (*Favosites*) occur in these rocks on both sides of the Arctic

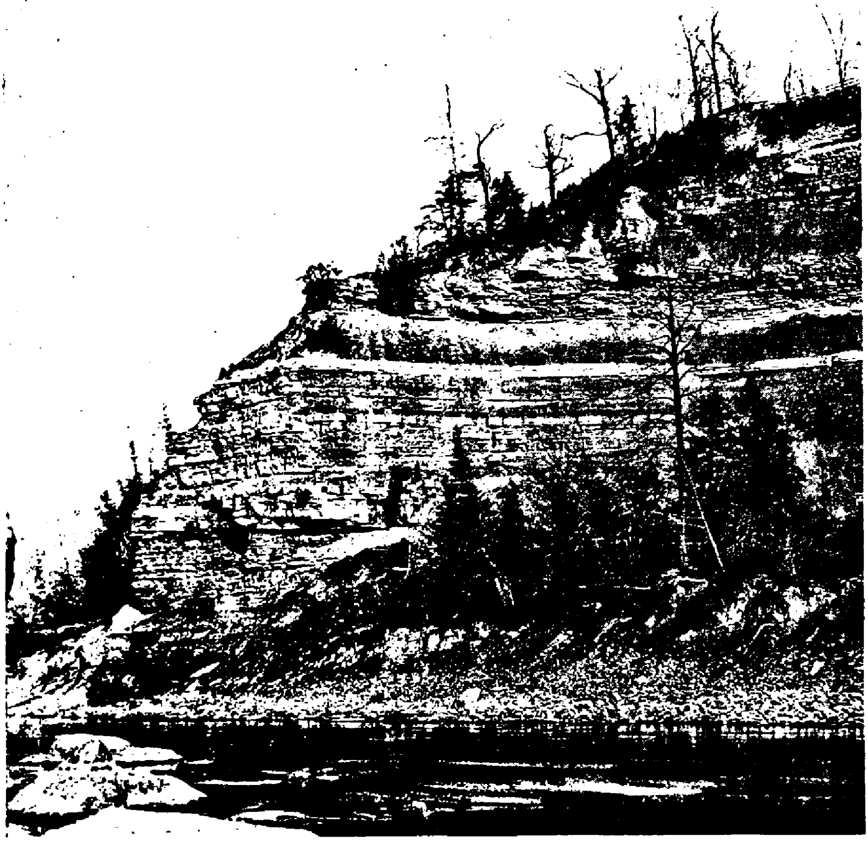


FIG. 246. Cañon of the Genesee River, below Lower Falls, Rochester, New York. The white band and all below it belong to the Medina formation; the strata above are Clinton. All Lower Silurian. (Gilbert, U. S. G. S.)

Ocean, occurring in one instance at Polaris Bay, 81° north latitude.

Silurian rocks have also been detected in China, North Africa, and some localities in South America and Australia. Some of the rocks of the Table Mountain sandstones of South Africa are thought to be Silurian. "In all these areas, as also in North America, the fossils resemble those of the Northern European division, rather than those of the Southern." (Scott.)

With such an abundance of Silurian corals in many parts of the arctic regions, it is impossible to avoid the conclusion that the climate represented by these remains must have been very uniform over the entire earth, with no indication of distinct climatic zones, as we have at present.

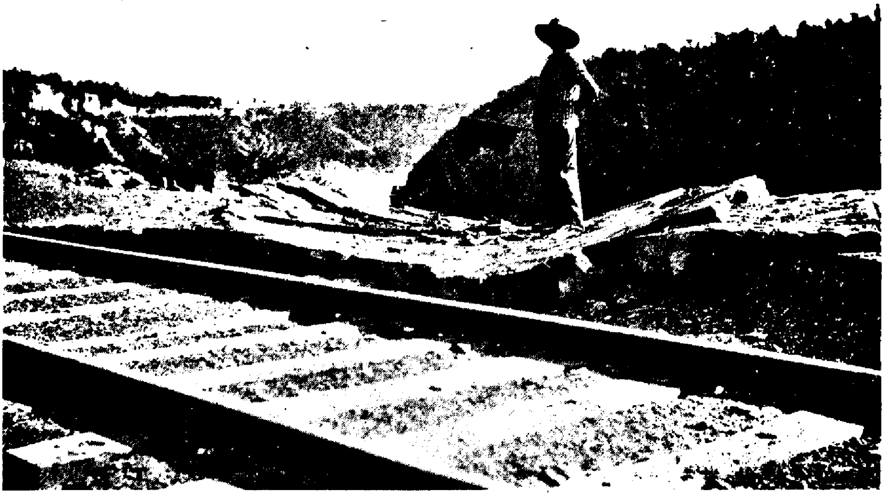


FIG. 247. Remnant of a giant ripple mark, in Medina sandstone (L. Silurian), New York Central Railway, Niagara Gorge, New York. This is nearly 20 miles west of the locality shown in Fig. 248. Probably these phenomena prevailed in the Medina sandstone over all this region. (Gilbert, U. S. G. S.)

Life

Very many of the Silurian rocks are packed full of fossils; but as a rule, they do not show any great variety of types, except a profusion of marine invertebrates, chiefly *corals, crinoids,*

FIG. 248. Giant ripple marks in Medina sandstone (L. Silurian), Lockport, New York. These are manifestly quite abnormal. They could have been caused at the bottom of very deep water — perhaps a mile or more deep — if a gigantic tidal wave was moving through the ocean. It is difficult to see how else they could have been made. (Gilbert, U. S. G. S.)

bryozoans, brachiopods, and *trilobites.* Nautiloids are fairly common in America, nearly one hundred species having been described from here; but in Bohemia, which represents the Southern European group of Silurian beds, Barrande described from this small area 1,150 species. This represents the greatest number of nautiloids found anywhere in the rocks. The present *pearly nautilus* is but the lonely survivor of great tribes

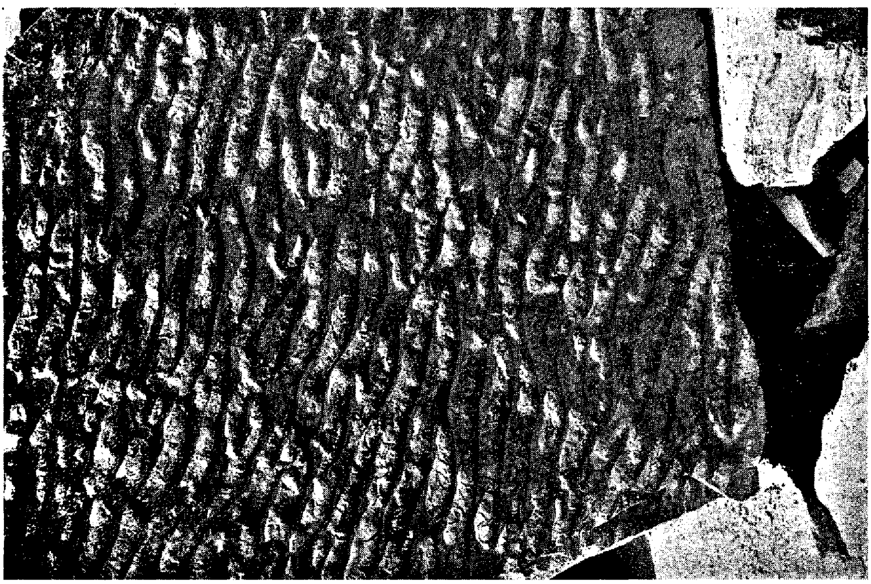


FIG. 249. Ripple marks on sandstone, Berea, Ohio. These are normal, that is, formed in shallow water. Compare these with those in Figs. 247, 248. (Gilbert, U. S. G. S.)

of similar creatures which used to flourish in the ancient seas. If we judge by the habitat of this modern nautilus, the ancient representatives of the family probably lived at considerable depths. The shales containing graptolites and the sponge-bearing cherts found in many of the Silurian formations, may also represent rather deep waters. Some fifty-two species of dendroid graptolites occur at Hamilton, Ontario.

About 400 kinds of *crinoids* are known from the Silurian rocks of America. They must have thronged the waters in certain localities, for we have many thick limestones composed largely of their broken skeletons. The modern crinoids do not live together in colonies in such a way as to contribute to the making of limestones, and most of the modern kinds live in rather deep waters, some of them two or more miles down. We

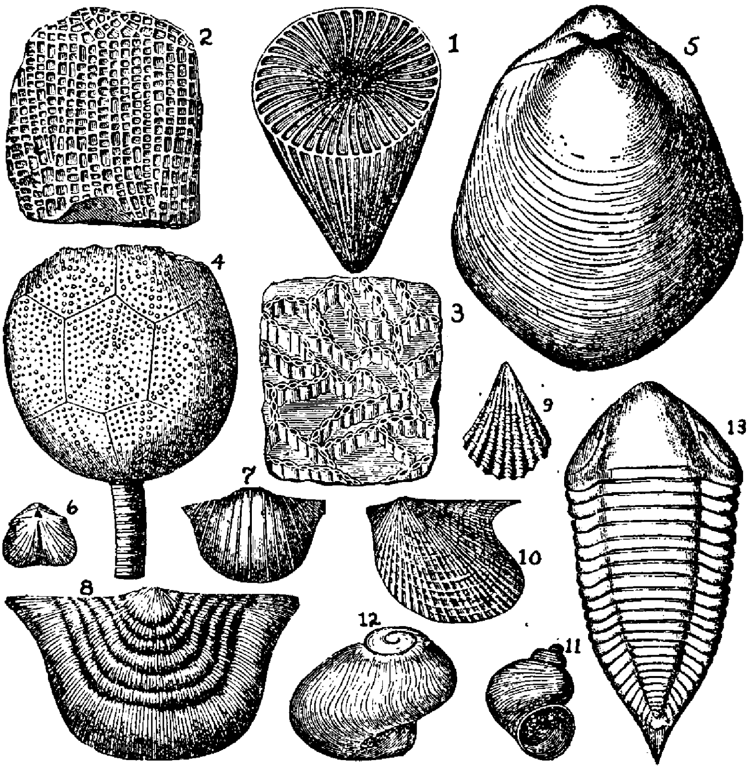


FIG. 250. SILURIAN FOSSILS

CORALS: 1, *Zaphrentis bilateralis;* 2, *Favosites niagarensis;* 3, *Halysites catenulatus.* CRINOID: 4, *Caryocrinus ornatus.* MOLLUSKS: 5, *Pentamerus oblongus;* 6, *Orthis biloba* (× 2); 7, *Leptæna transversalis;* 8, *Strophomena;* 9, *Rhynchonella cuneata,* United States and Great Britain; 10, *Avicula emacerata;* 11, *Cyclonema cancellata;* 12, *Platyceras angulatum.* ARTICULATES: 13, *Homalonotus delphinocephalus.* (After Dana.)

can not always be sure of the environment in which these ancient animals lived.

Many forms of *bryozoans* occur in these beds, a typical group of them being seen near the railway track in the gorge of the Niagara River.

Some 350 kinds of *brachiopods* have been described from the Silurian rocks of America. They resemble in a general way the similar species of the Ordovician.

About 150 American species of *trilobites* have been described, many of which were strange-looking creatures with huge spines on their heads and tails.

Eurypterids, or "sea scorpions," are quite common in the Silurian rocks. The largest of them was found in New York, and has been reported to be 9 feet in length. They seem to have

lived in water not far from the shore, and are not often associated with any other fossils.

Corals are plentiful in the limestones of the Middle and the Upper Silurian. Splendid examples of these ancient corals are to be seen in Iowa, Wisconsin, the Manitoulin Islands, and at Louisville, Kentucky. They belong to the groups of *tabulate* corals and those of four sets of septa, or the *Tetracoralla,* as described in the preceding chapter. *Gastropods* and other shellfish are often found associated with the corals, as is the case in the reefs of the present day.

So far as the Lower Silurian rocks are concerned, it seems that each area had more or less of its own peculiar assemblage of life. But the fossils found in the Upper Silurian beds are much more cosmopolitan. At least 30 species seem to be the same in Northern Europe and in America.

Some few *fishes* occur in the rocks of the Upper Silurian, but the description of the fishes will be postponed until the next chapter. Fishes are so plentiful in the rocks of the next, the Devonian system, that the old geologists used to speak of them as representing an "Age of Fishes."

Geologists have been somewhat puzzled at finding many examples of *scorpions* in the Silurian rocks. They were very

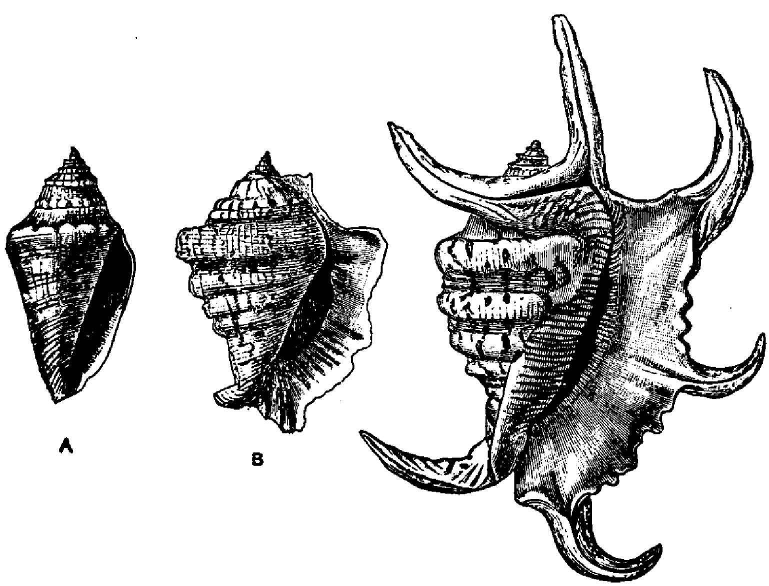


FIG. 251. Three stages in the growth of *Pterocerus rugosum*, Sowb., East Indies, showing the development of the "fingers." (After A. H. Cooke, in "Cambridge Natural History.") If these were found fossil, how natural it would be to place them not merely in separate species, but in distinct genera!

much like living scorpions, though the largest one yet known was only about 2.5 inches long. As scorpions are strictly carnivorous land animals, and as no insects, spiders, or even land snails have yet been found in any of the Silurian rocks, or in any of the preceding systems, the question naturally arises, What did these Silurian scorpions live on? This interesting question has not yet received a satisfactory answer, from the point of view of evolutionary geologists.

Salt and Gypsum Beds. Rock salt and gypsum are associated with the Silurian (Salina formation) in various parts of New York, Ohio, and Ontario. Similar beds, even much thicker, occur near Berlin, in Germany, and at Stassfurt, in Southern Saxony. These latter beds are over 3,000 feet in thickness; but they are classed as belonging to the Permian system. Much speculation has been indulged in regarding the way in which these beds may have been formed in arid climates, by the slow evaporation of confined lakes. As these beds contain absolutely no fossils, we can not even be sure that they are really of fossiliferous age. They may represent primitive or original formations. At least, all the speculations in reference to their formation are of little value.

"Extinct" Species. It is difficult to refrain from saying that we do not know how many of the genera and species represented in these Silurian rocks may be alive to-day. We have already mentioned the absurd and unfair custom of giving *new names* — that is, names different from those of modern similar genera and species — to all the fossils found in these so-called "old" rocks. Only some seven or eight genera of rhizopods, brachiopods, and mollusks are mentioned in geological literature as having living representatives; but doubtless by a little impartial comparison, large numbers of other forms might easily be shown to be identical with their modern relatives.

The following remarks of Heilprin are worth repeating here:

"It is by no means improbable that many of the older genera, now recognized as distinct by reason of our imperfect knowledge concerning their true relationships, have in reality representatives living in the modern seas. . . .

"However divergent may be the views of authors on the matter of relationship, it is practically certain that numerous forms of life, exhibiting no distinctive characters of their own, are constituted into distinct species for no other reason than that they occur in formations widely separated from those holding their nearest kin."—*"Geographical and Geological Distribution of Animals," pp. 207, 208, 103, 104.*

CHAPTER XXVI

Fossil Fishes

Definition. The word *fish* is derived from the Latin *piscis;* and among the Romans, the latter was applied to any animal that lives entirely in the water. We have a reminder of this use of the word in such terms as *shellfish, starfish,* and *jellyfish,* these terms referring to animals which are wholly different from real fishes in every way.

Structure. Among naturalists, the class *Pisces* includes only the true fishes, all of which have a backbone and other structures always associated with the backbone. Fishes do not have a movable neck, but they do have a distinct or movable lower jaw, which works on a hinge joint. As their blood remains of about the same temperature as that of the water in which they live, they are called cold-blooded, in this respect resembling the amphibians and reptiles which do not live in the water.

All fishes have *gills,* with which to absorb oxygen from the water; and they have fins, with which to propel themselves through the water. Most fishes have an air bladder, which serves the purpose of a float or a hydrostatic organ. By enlargement or contraction of this air bladder, the size of the animal is increased or diminished; and thus it can rise or sink in the water, just as the same thing can be accomplished in a Cartesian diver, or in a submarine. Some fishes use the air bladder to assist the gills in respiration, absorbing oxygen from its surface. Other fishes, the *Dipnoi,* or lungfishes, have true lungs in addition to their gills, and can live indefinitely out of the water, breathing air like a land animal.

The general outline of a tapering form is much the same in all fishes, though there are some kinds which depart widely even from this general shape. The skin of most fishes is protected by overlapping scales or by bony plates called *scutes,* or even by an elaborate set of spines; though in some forms, the skin is soft and unprotected by covering. The fins are variously arranged, and are used for steadying or steering the body; but the chief organ for propelling the fish forward is the tail, which is flexible, strong, and a very efficient organ for locomotion, acting much like a sculling oar at the rear of a boat, but many times more effectually.

Subdivisions. There are three general types of tails in fishes; and as the classification of fishes is made to depend con-

siderably upon these distinctions, it will be worth while to note these three types.

1. The *Diphycercal* or Symmetrical Tail. In this, the vertebral column continues in a straight line to the extremity, with the joints, or vertebræ, constantly diminishing in size, and at the extremity is surrounded by a symmetrical tail fin. This type is found commonly among Devonian fishes, and is seen in the early stages of many modern living fishes.

2. The *Heterocercal* or Unequally Lobed Tail. In this type, the end of the spinal column turns upward toward the dorsal side at the very end, terminating in a series of diminishing joints in an upper lobe only, the corresponding lower lobe being wanting.

3. The *Homocercal* or Two-Lobed Tail. This type is also usually symmetrical, with both lobes equal in size; and this is the more common type to-day among living fishes. In it, the spinal column ends quite abruptly, and the tail fins develop in such a way that the upper and lower rays are the longest, forming two more or less distinct lobes above and below.

In this chapter dealing with the subject of fossil fishes, it will be necessary to include some forms which by some authorities are not included in the class Pisces, but are separated off into one or more classes by themselves. Such are the lampreys, sharks, and rays or skates. Our classification of the fishes, accordingly, will be as follows:

Class Pisces, or true fishes.
Subclass *Elasmobranchii,* or cartilaginous fishes.
  Order *Acanthodii,* or spinous sharks.
  Order *Selachii,* or true sharks and rays.
Subclass *Ostracodermi,* or bony-skinned fishes.
Subclass *Dipnoi,* or true lungfishes.
Subclass *Arthrodira,* or armored fishes.
Subclass *Ganoidei,* or enamel-scaled fishes.
Subclass *Teleostei,* or bony fishes.

Elasmobranchs. The *Elasmobranchii,* or cartilaginous fishes, include the true sharks, ancient and modern, the sea cats (*Chimæræ*), and the skates and rays. The word *Elasmobranch* means *having platelike gills;* and most of these fishes are marine.

In most of them, the mouth is situated on the under side of the head. The tail is usually heterocercal; and the internal skeleton is cartilaginous, or does not harden into bone. The skin is covered with small pieces of material like the teeth in composition, with hard, shining enamel on the outside or tip, and with a core made of dentine, and a base sunk in the dermis and made of phosphate of lime. This kind of scale is the *placoid;* and when these scales are quite small and set closely together, they constitute the *shagreen* (meaning *rough mosaic*)

which is so often the only part of these fishes which remains as a fossil.

On each side of the body, back of the head, are five *gill slits*, which in the living sharks and their kin are either entirely uncovered, or covered merely with a flap of skin, never covered with a true bony *operculum*, as in the true fishes. The *median fins*, or those on the dorsal and ventral parts, usually have long, sharp spines composed of horn or bone; and these also are often found as fossils, together with the shagreen.

Unlike most other fishes, the elasmobranchs have a skull without joints or sutures, but composed of one entire cartilaginous piece. They have no swimming bladder; and a large part of the intestine is provided with a fold or spiral membrane on the inside, which thus increases its absorbing surface. This feature is often noticeable in the fossil forms that are well preserved, and is seen also in the existing ganoids and lungfishes.

Fin spines of elasmobranchs occur in the Silurian rocks of both America and Europe; 39 species are named from the American Devonian, 288 from the Mississippian, 55 from the Pennsylvanian, and 10 from the Permian. As already pointed out, such an arrangement as this is a purely artificial one, certain species being regarded as characteristic of the one or the other of these formations, and whenever found, they are used more or less as "index fossils," to determine the "age" of the given beds. Most of these sharks from the Paleozoic rocks had pavementlike teeth, belonging to the two general types, the *cochliodonts* and the *cestracionts;* examples of the latter form being seen in the living Port Jackson shark (*Cestracion philippi*) of Australia. These pavementlike teeth are adapted to crushing crustaceans and shellfish, on which the living Port Jackson shark subsists, and because of which it has received the name of "oyster crusher."

Sharks like those more common to-day are found in the Mesozoic rocks, and are seen in a great variety of forms. Sharp-cutting teeth like those of modern sharks are found in the Miocene beds of South Carolina; and some of them are nearly 6 inches long, evidently belonging to an animal 60 feet long. The great blue shark of our present oceans sometimes attains a length of 40 feet. As all fishes and reptiles grow in size as long as they live, the size of any given species is more or less an index of the age of the specimen.

Ostracoderms. The *Ostracodermi,* or armored fishes with *bony skins,* as the word really means, are an extinct group, and found as fossils only in the Ordovician, Silurian, and Devonian

rocks. They are thought to have been adapted to feeding on the bottom of the sea, and are regarded as of sluggish habits. The head was broad and depressed; and both it and the whole posterior part of the body were covered with heavy scaled or placoid plates, which in some species became fused into thick plates of bone. The posterior part was often unprotected, though in some species it also was covered with plates or scales. Some species had large paddles or swimming limbs (not true fins) on the sides; and these were covered with the usual plates or scales. None of these fishes had any internal skeleton whatever; and on this account, naturalists have had great difficulty in classifying them. As fossils, they are very widely distributed.

Lungfishes. The *Dipnoi* (Greek, *double breathing*), or lungfishes, which have survived to our day are divided into three genera, and are found in South America, Central and Western Africa, and Australia. They are sluggish animals; and in times of drought, they inclose themselves in a case or rude cocoon of mud, and survive without food for months, breathing air through an opening in the mud. The skeleton is mostly cartilaginous, though somewhat ossified; and the tail is either diphycercal, as in modern dipnoans, or heterocercal, as in most of the fossil types.

About 15 species of dipnoans occur in the Devonian of both America and Europe. They are also found in the Carboniferous, Triassic, and Jurassic, but it seems that they are not found in any of the "later" fossiliferous strata. When the modern forms were discovered, about fifty years ago, they were looked upon almost as if brought back from the dead; and it was considered very wonderful how they could have "persisted" into our modern world. Why they have skipped all the strata from the Mesozoic down to the modern, is a problem for evolutionary geology to solve.

Armored Fishes. The *Arthrodira* (Greek, *jointed neck*) are named from a rare feature in the neck region whereby the head could move up or down, by the armor of the head sliding over that of the body, an arrangement similar to that of the ostracoderms. They were heavily armored fishes, found in enormous numbers in the Devonian and other Paleozoic rocks; and they were the largest and most formidable fishes found in these rocks. Instead of true teeth, they had plates for *crunching* or shears for cutting; and if they were as savage as their appearance would indicate, they must have been very cruel monsters. One form, *Dinichthys* (Greek, *terrible fish*), was over 20 feet long, and is common in the Devonian rocks. Another species,

Titanichthys clarki, was even larger, with a head over four feet wide, and with a lower jaw a yard long.

Hugh Miller, a Scotch geologist of a half century ago, has described in a very picturesque way the great multitudes of *Pterichthes* which are found in the rocks in various parts of Scotland. It is not so much the size that he dwells upon, for many of the specimens in these rocks are not large; but he emphasizes the way in which the figures of the fish are contorted and twisted around as if the fish had been in convulsions and had been buried alive by the sediments in which it is now inclosed. He says that the innumerable existences over an area more than one hundred miles in length must all have been "annihilated at once," and he expresses great wonder as to how such a thing was brought about. But it is a still more remarkable fact that wherever these fishes are found throughout the world, they occur in practically this same condition. Much the same thing is true of the other kinds of fishes found in the other geological formations. In other words, the evidences of violent and sudden death are to be seen in connection with almost all the remains of fossil fishes, wherever they are found.

By some, the Arthrodira are classed with the Dipnoi, or lungfishes. More than 40 species are named from North America.

Ganoids. The *Ganoidei* (Greek, *bright appearance*), or enamel-scaled fishes, are familiar from the living gar pikes and sturgeons of the fresh waters of North America. The glossy appearance of these fishes is due to the bright enamel, like the outer covering of the teeth of mammals, which covers the scales. The scales of the ganoids have but two layers, the enamel layer and the bony one; they lack the dentine layer, which is found in the scales of the cartilaginous fishes. Some of the ganoids, however, have true elastic cycloid scales, as in the bony fishes, or *teleosts*, to be mentioned presently. They have diphycercal or heterocercal tails, and have a spiral valve in the intestine.

The ganoids are divided into two orders, the divisions being based on the types of fins. These two orders are: (1) the *Crossopterygii*, or those with fringe fins or lobed fins; and (2) the *Stylopterygii*, or those with the pillarlike fins. There are but two living genera of the first order, and both of these genera inhabit the fresh waters of Africa. One of them, the *Polypterus*, or *bichir*, of the Nile and other waters of Central Africa, is a well-known food fish of that region. The air bladder of these fishes has some of the functions of a lung; but these fishes can not live out of the water more than a few hours.

The pillar-finned ganoids are the type prevailing to-day in our northern lakes and rivers, as, for instance, in the Great Lakes of North America.

The crossopterygians are the most common fishes found in the Lower Devonian rocks. They are divided into a great many genera. The stylopterygians are more common in the Mesozoic rocks, and especially in the Jurassic.

Teleosts. The *Teleostei* (Greek, *true bone*), or bony fishes, include most of the fishes caught for sport or for commercial purposes; and they are found in all our modern rivers, lakes, and oceans. As a rule, they are covered with thin, elastic, cycloid scales. In such forms as the eels, the skin is naked and slimy. The tail is usually homocercal. The internal skeleton of all these fishes is completely ossified, and the vertebræ are hollow at both ends.

Fossils of this class are fairly common in the Cretaceous and Tertiary rocks. Herrings, mullets, catfishes, cod, and salmon are found in the Cretaceous. Naturally enough, the rocks in which any such fishes are found could not be classed as Paleozoic, or even as "early" Mesozoic.

At Lompoc, California, is a deposit of diatoms covering some four square miles in area, and originally much larger, because this is simply the remnant left after a considerable amount of erosion. In the beds of this deposit of diatoms are found immense numbers of *Xyne*, a kind of herring, which have been buried here by the diatom ooze falling upon and around them and thus burying them alive. Other well-known localities where fossil fishes have been found in great numbers are, Glarus, Monte Bolca, and many other places in Europe, together with the Onondaga black limestones of Ohio and Michigan, and the Green River shales of Arizona, with many others.

CHAPTER XXVII

The Devonian System

History. For over a hundred years, the strata which in England occur between the Coal Measures and the old transition rocks were popularly known as the *Old Red Sandstone,* which, like another somewhat similar bed above the Coal Measures, and known as the *New Red Sandstone,* is widely distributed through the British Isles. Hugh Miller (Fig. 252), a stonemason of Cromarty, Scotland, was one of the first to give a scientific description of these beds. Soon afterwards (1837) Sedgwick and Murchison described extensive beds in Devonshire, Southern England, which were supposed, from the evidence of their fossils, to belong *between* the Silurian and the Coal Measures. A little later Murchison traveled through Russia, and there he found beds which seemed to bridge over the sharp contrast between the Old Red Sandstone of Scotland and Northern England, and the Devonian of Devon and Cornwall in the south of England. In this way, all these three groups were united into one system, since known as the *Devonian system.* Quite full sections of the Devonian beds are also found in Belgium and in the valley of the Rhine; but for America, the exposures in the New York region are taken as the standard, more than one half of the State of New York being covered with Devonian rocks.

Subdivisions. The following are the chief subdivisions of the Devonian rocks in America:

Upper Devonian	Chautauquan Series	Chemung-Catskill formations
	Senecan Series	Portage formations Naples, Ithaca, and Oneonta beds Genesee-Tully formations
Middle Devonian	Erian Series	Hamilton formation
	Ulsterian Series	Marcellus-Onondaga formations Schoharie-Esopus formations
Lower Devonian	Oriskanian Series	Oriskany-Port Ewen formations
	Helderbergian Series	Helderberg formations

Distribution. The *Helderberg limestones* extend, with various interruptions, from Southwestern Virginia, along the line of the Appalachians to Albany, New York. These rocks are extensively developed in Northern Maine, Southern New Brunswick, and in parts of Nova Scotia. In the Gaspé Peninsula,

at the mouth of the St. Lawrence River, are found 1,500 feet of limestones representing the Helderbergian and Oriskanian series. Fossils of these rocks have been found in the arctic regions, at 80° north latitude.

The *Oriskanian series* are chiefly sandstones. They are thickest in Western Maryland, and thin away both to the north and to the south from that center. In the Mississippi Valley, the Oriskany is found in about the same region as the limestones of the preceding series, but it extends into Northern Georgia and Alabama. Limestones of this series also occur in the Maritime Provinces of Canada, where they are said to be 5,000 feet thick. Many of the fossils of these latter rocks are identical with the Devonian beds of Belgium and the Rhine Valley in Europe.

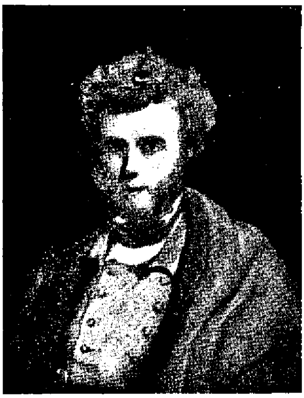


FIG. 252. Hugh Miller (1802-1856), Scotch geologist; author of "The Old Red Sandstone."

The *Onondaga limestone* extends, with some interruptions, from the Hudson River across New York into Michigan, and circling around, it runs through Indiana, Illinois, and Kentucky. Extensive developments of these rocks are found near the mouth of the Mackenzie River, in the arctic regions; with interruptions, these rocks extend down across the Dakotas, Nebraska, and Kansas, into Iowa, Minnesota, and other parts of the upper Mississippi Valley. These limestones are largely of coral formation; and at such places as the falls of the Ohio, above Louisville, Kentucky, specimens of the corals are most beautifully preserved. Such localities are often spoken of as representing an old coral reef. But doubtless, while the materials came from such a coral reef, they have been rearranged and spread out by subsequent movements of the waters. Professor Eduard Suess, in describing the coral beds of Central Europe, uses the following language; and probably these words will be just as applicable to these coral deposits here in America:

"Notwithstanding the abundance and variety of the corals, sometimes forming really large isolated growths, I have never seen anything in these localities which could be called a true coral reef. The corals lie heaped together, with shells, in tuffs, or marls, that is, always in clastic sediments. . . . These also, so far as I have been able to observe them, have rather the appearance of thick beds than of true reefs."—*"The Face of the Earth," Vol. 2, pp. 321, 322.*

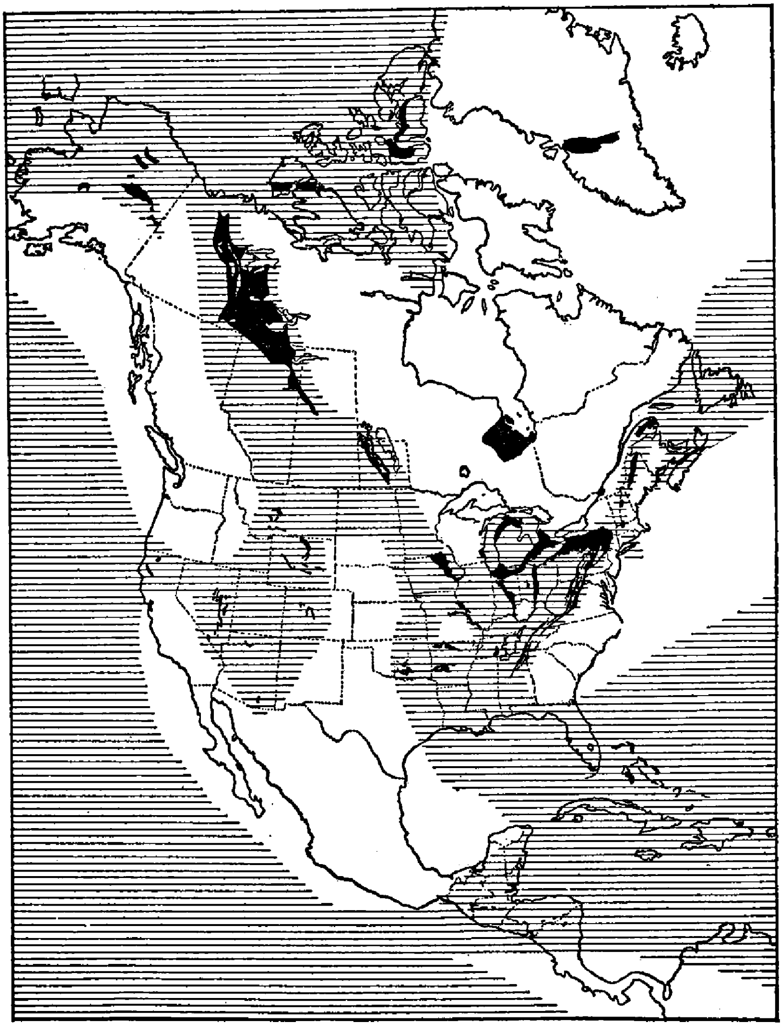


FIG. 253. Map of the Devonian outcrops in North America, which are shown in black. White areas, unknown. (After W. B. Scott, "Introduction to Geology," permission of Macmillan Co.)

The Upper Devonian beds have much the same distribution as those already mentioned. The *Genesee shales* are black and quite carboniferous. They extend from Lake Erie to Central Pennsylvania. The *Portage series* is associated with it; and in Western New York, they have between them a limestone which contains the famous assemblage of animals called the "*Naples fauna*." Fossils similar to these have been found from Mani-

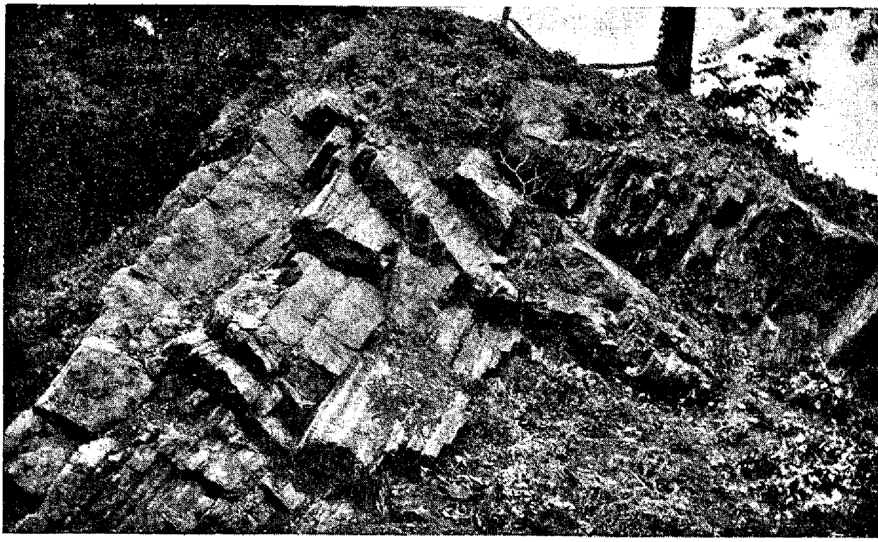


FIG. 254. Helderberg limestone (L. Devonian), in a railway cut, three fourths mile north of Daw, Virginia. (Hinds, U. S. G. S.)

toba through the northwest of America into Siberia, and from there through Russia into Westphalia, Germany.

The *Chemung* comprises a mass of sandstones and con-

FIG. 255. Oriskany sandstone (L. Devonian), in a cut of the Pennsylvania Railway, west of Huntingdon, Pennsylvania. (Butts, U. S. G. S.)

FIG. 256. Middle Chemung (U. Devonian) rocks, at Hawns Bridge, Pennsylvania. Shale, with thin, hard sandstone layers. Looking northeast. (Butts, U. S. G. S.)

glomerates, of maximum thickness in Pennsylvania, but thinning out toward the west.

Devonian rocks do not seem to occur in the Great Plains region; and in Colorado also, they seem to be absent, the Carboniferous strata resting upon Cambrian and Ordovician. However, in the plateau region are many outcrops of Devonian beds, as in the Grand Cañon region, in the Wasatch Mountains, and in Nevada.

Many facts connected with these ancient rocks seem to favor the hypothesis of an alternating tidal action, with its regular ebb and flow, as a possible explanation of the peculiar way in which limestones and sandstones alternate with one another.

"Comparing the rocks of the Ordovician, Silurian, and Devonian, as these are developed in the Appalachian and adjoining regions, a certain rhythmic or periodic recurrence of events may be discovered among them. Each system is characterized by a great and very widespread limestone formation, the Trenton, Lockport-Guelph, and Onondaga, respectively, and in each the limestone is succeeded by shales or other clastic rocks, the Utica, Salina, and Portage, due to an increase of terrigenous material, and each was closed by a more or less widespread emergence of the sea bottom.

Each began with a subsidence which gradually extended to a maximum at the time when the great limestone was formed. The parallelisms are not exact, but they are certainly suggestive."— *Scott.*

As already remarked, Devonian rocks are extensively shown in Southwest England, in Belgium, and in Germany; and they are very widespread in Russia, both in European Russia and

FIG. 257. Cliff of Devonian rocks on the shore of Lake Erie, south of Buffalo. This view is typical of the rock exposures on the lake shore from Buffalo to Cleveland. (After Grabau.)

in Siberia. Devonian limestones composed of coral rocks are found extensively in the Alps, also in Spain and in Portugal.

Devonian areas have been reported from China, the Altai Mountains, from Asia Minor, and from Northern Africa. In South America also, occur wider areas of Devonian strata than those of any other Paleozoic system.

According to the evidence already given, the climate must have been mild and uniform over all the earth when these extensive limestone beds were formed in the arctic regions.

Life

Plants. A great abundance of plant life is found in the Devonian beds in many parts of the world. All the higher

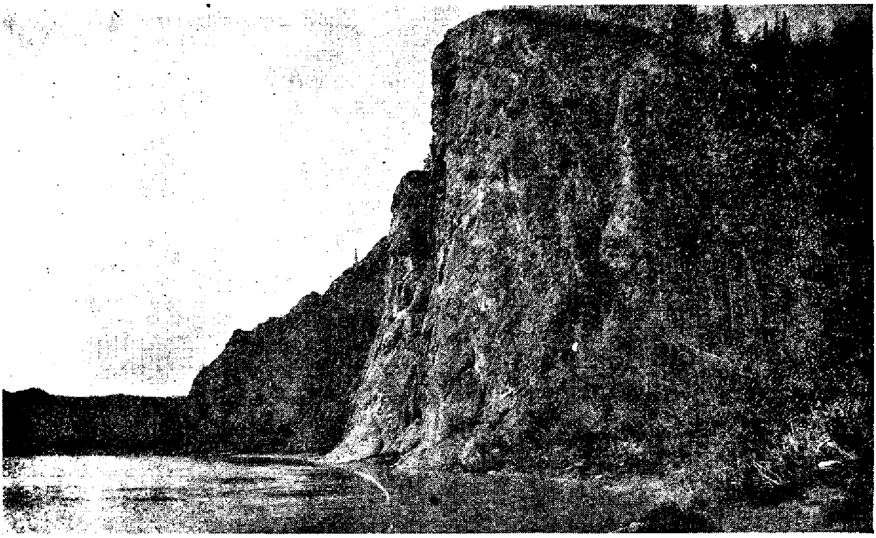


FIG. 258. Cliff of Devonian limestone, on the Yukon. (Blackwelder, U. S. G. S.)

cryptogams are found, but chiefly ferns, lycopods (club mosses), and Equisetaceæ (horsetails). Many examples of Cycadofilices are also found in these Devonian beds. But as these plants are largely concerned in the formation of the coral beds of the subsequent Carboniferous system, a further description of them will be postponed until another chapter.

Invertebrates. *Graptolites* are not found in any great abun-

FIG. 259. Upper Devonian strata from the type section, Cornwall, Southwest England. These beds are alternating shales and limestones. (After Lake and Rastall.)

dance in the Devonian rocks, but *corals* are even more plentiful in these than in the systems already spoken of.

Of the *Echinodermata,* the cystoids and the blastoids are not very plentiful, but the crinoids and starfishes are found in great variety and in immense numbers. The remains of crinoids contributed largely to the making of immense limestone deposits of the Devonian system.

The *trilobites* are less plentiful in the Devonian than in the preceding systems. One of these, *Terataspis,* is one of the largest and most elaborately ornamented of all the trilobites.

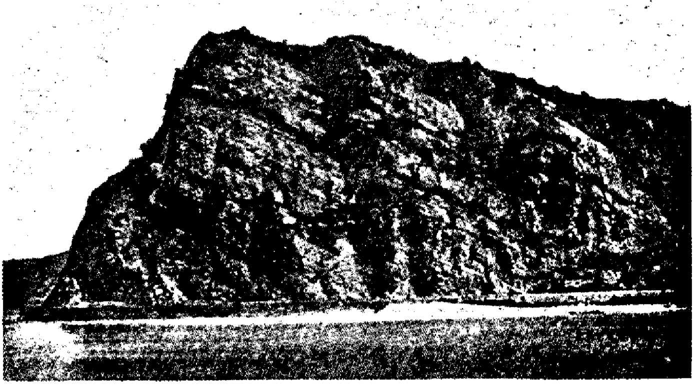


FIG. 260. The famous Lorelei Rock, on the Rhine, formed of inclined Devonian sandstones and shales.

Most of the Devonian trilobites exhibit more or less oramentation on the margin of the head, while they usually have a development of spines on both tail and head.

The *eurypterids,* another family of crustaceans, are found in great abundance in the Devonian rocks. Some of them were gigantic creatures, being six feet long. Insects are occasionally found, though they are not common.

Brachiopods are the most abundant fossils found in the Devonian, in respect both to species and to numbers. Of these, some of the most characteristic genera are *Spirifer, Hypothyris, Athyris, Gypidula, Vitulina,* and those belonging to the large family of *Terebratulidæ,* many genera of which are still living in our modern seas.

Of the *Mollusca,* the ammonoid division of the cephalopods are found occasionally in Devonian beds. These are distinguished from the nautiloids by the complex sutures, or lines, made by the junction of the septa, or internal partitions, with

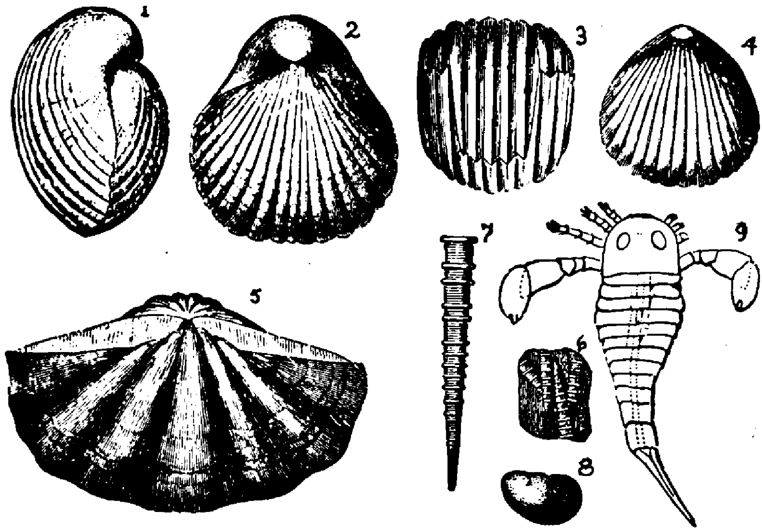


FIG. 261. SILURO-DEVONIAN FOSSILS

BRACHIOPODS: 1, 2, *Pentamerus galeatus;* 3, 4, *Rhynchonella ventricosa;* 5, *Spirifer macropleurus.* PTEROPOD: 6, *Tentaculites gyracanthus;* 7, *the same,* enlarged. OSTRACOID: 8, *Leperditia alta.* ARTHROPOD: 9, *Eurypterus remipes,* a small specimen. 1-5 are species from the Devonian; 6-9, from the Silurian. (After Dana.)

the outer wall of the shell. Some of these ammonoids had straight shells, like that of *Orthoceras* already mentioned from the Ordovician and Silurian strata.

Fishes. Among the most interesting fossils found in the Devonian beds are the *fishes.* So numerous are they and so splendidly preserved that these beds used to be assigned to an

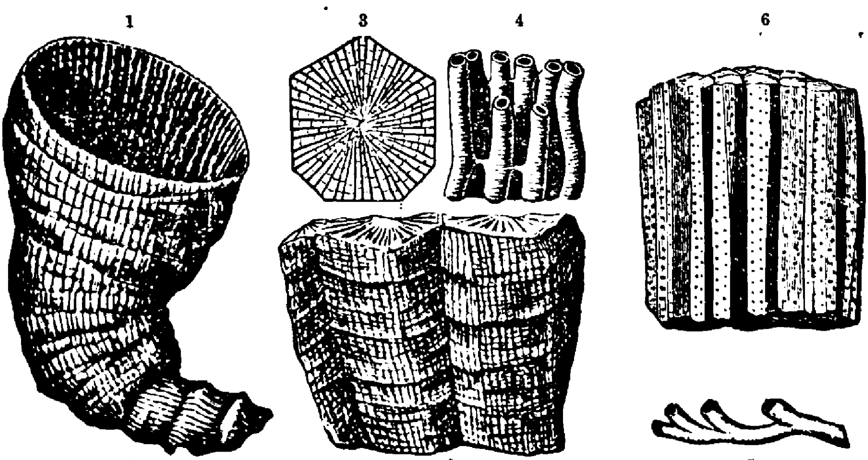


FIG. 262. Devonian corals. 1, *Zaphrentis rafinesquii;* 2, 3, *Cyathophyllum rugosum;* 4, *Syringopora maclurii;* 5, *Aulopora cornuta;* 6, *Favosites goldfussi:* all of the Onondaga limestone, Middle Devonian. (After Dana.)

FIG. 263. Natural casts of Atrypa, Spinosa, Spirifer, Rhynchonella; Pelecypods; and Tentaculites. Hamilton fauna (M. Devonian). (Hardin, U. S. G. S.)

alleged "Age of Fishes." A description of this great group has already been given in the preceding chapter. Here a description of some of the fossil fishes characteristic of the Devonian beds will be sufficient.

The ostracoderms are often called fishes; but as they had neither true jaws nor paired fins, and as they had no internal skeleton whatever, the mere fact that they had the outward appearance of fishes, and also had their body covered with heavy plates of bony material, would not make them fishes in the true sense of the word. But we must place them here among the fishes, for we do not know what else to do with them. One of the most remarkable of these near-fishes is the *Pterichthys*, found in great numbers in the Old Red Sandstone of Scotland, and so picturesquely described by Hugh Miller.

Of the true fishes, there are selachians, or sharks, with Dipnoi, or lungfishes, and the terrible *Dinichthys* and *Titanichthys*, the latter being some 25 feet long and having a head 4 feet wide.

The following is Hugh Miller's description of the fishes of the Old Red as found in Scotland, and we should remember that the condition in which the Devonian fishes are found in various other parts of the world is not particularly different:

"The river bullhead, when attacked by an enemy, or immediately as it feels the hook in its jaws, erects its two spines at nearly right angles with the plates of the head, as if to render itself as difficult of being swallowed as possible. The attitude is one of danger and alarm; and it is a curious fact, to which I shall have occasion afterwards to advert, that in this attitude nine tenths of the Pterichthes of the Lower Old Red Sandstone are to be found. . . . It presents us, too, with a wonderful record of violent death falling at once, not on a few individuals, but on whole tribes. . . .

"At this period of our history, some terrible catastrophe involved in sudden destruction the fish of an area at least a hundred miles from boundary to boundary, perhaps much more. The same platform at Orkney as at Cromarty is strewed thick with remains, which exhibit unequivocally the marks of violent death. The figures are contorted, contracted, curved, the tail in many instances is bent round to the head; the spines stick out; the fins are spread to the full, as in fish that die in convulsions. . . . The record is one of destruction at once widely spread and total, so far as it extended. . . . By what quiet but potent agency of destruction were the innumerable existences of an area perhaps ten thousand square miles in extent annihilated at once, and yet the medium in which they lived left undisturbed in its operations?

"Conjecture lacks footing in grappling with the enigma, and expatiates in uncertainty over all the known phenomena of death."—*"Old Red Sandstone," pp. 48, 221, 222.*

But it is not only evident that all these innumerable existences were annihilated at once, it is also equally evident that they were all *buried alive, or at least buried before decomposition had ensued.* They were obviously entombed by the sediments in which we find them buried.

The problem of how this happened must be left over until we have the data before us regarding the various other phenomena of geology; for we wish to frame an intelligent induction regarding these phenomena in general, and do not wish to prejudice the case by deciding on one or two particular phenomena beforehand. We must deal with the world as a whole, and not with a few isolated patches of strata here and there.

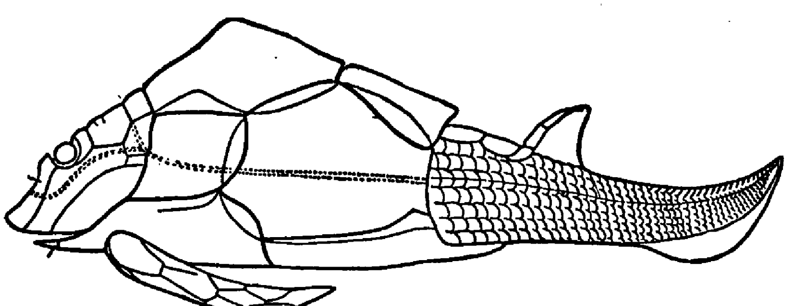


FIG. 264. *Pterichthys testudinarius*, restored. Old Red Sandstone. (After W. B. Scott, "Introduction to Geology," permission of Macmillan Co.)

CHAPTER XXVIII

The Carboniferous System

Historical. For over a hundred years, the miners and others connected with mining operations in England have been familiar with what they have called the *Coal Measures.* In many places, these Coal Measures were underlain by a coarse, gritty sandstone, known as the *Millstone Grit,* from the uses to which it was frequently put. Below both of these, or directly below the Coal Measures when the Millstone Grit happened to be absent, was usually a series of sandy and shaly beds containing either marine fossils or plant remains, sometimes both. These latter were called the *Culm;* or occasionally when this also was absent, there would be a limestone series, which was accordingly called the *Carboniferous Limestone.* This latter was also even more frequently called the *Mountain Limestone,* because in the west of Britain and in Ireland it formed the tops of many hills and ridges.

The name *Carboniferous* was first proposed by Conybeare, in 1822; and from this date onward, these beds below the Coal Measures came to be known as the *Lower Carboniferous series,* a name which still attaches to them in many countries of Europe. In America, these beds or their equivalents were early called the *Sub-Carboniferous;* but later the name *Mississippian* began to be applied to them, the name having been suggested by Winchell in 1870, because these beds were found well developed in the upper part of the Mississippi Valley. Similarly the name *Pennsylvanian* was proposed by H. S. Williams in 1891 for the Carboniferous proper, or the Coal Measures; and these names have gained their way so much in America that they are now established as the equivalents of *Lower* and *Upper Carboniferous,* as the latter are still used in Europe. On the Continent of Europe, the name *Dinantian* (from Dinant, on the Meuse, Belgium) is usually applied to the Lower Carboniferous, while the name *Carbonic* is used for the real Coal Measures.

These names may be conveniently placed side by side in a table to show their equivalent usage:

America	*England*	*Continental Europe*
Pennsylvanian	Upper Carboniferous	Dinantian or Culm
Mississippian	Lower Carboniferous	Carbonic

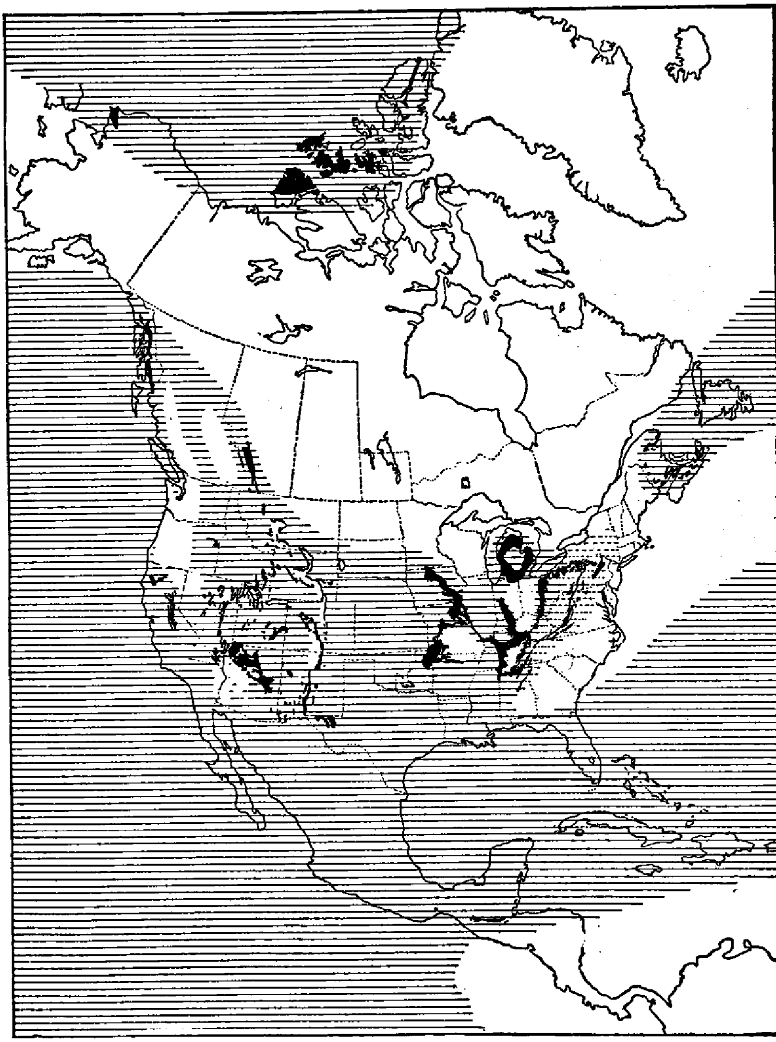


FIG. 265. Map of the outcrops of the Lower Carboniferous (Mississippian) strata, indicated in black. (After W. B. Scott, "Introduction to Geology," permission of Macmillan Co.).

Mississippian

Distribution. The New York rocks which have so long served as the standard of comparison and correlation of the strata, no longer furnish a standard scale for the rocks of the Carboniferous system; for the rocks of New York have nearly all been included under the other systems which we have already examined, and very few of the "later" systems are found there. The standard scales for these subdivisions of the Car-

FIG. 266. Exposure showing Fountain formation (Pennsylvanian) resting on the granite, west of Lyons, Colorado. (Stanton, U. S. G. S.)

boniferous are found in Pennsylvania and in the Mississippi Valley. Carboniferous rocks are also found over much of the western part of America; but they are wholly marine deposits, and contain no coal. The following table will show the subdivisions of the Mississippian rocks:

Mississippi Valley	Ohio	Eastern Pennsylvania
Upper Mississippian or Chester Series	(Stratigraphical break) Maxwell limestone	Mauch Chunk red shales and sandstones, with Greenbriar limestone in some localities
Middle Mississippian or Meramec Series	(Stratigraphical break)	
Lower Mississippian or Osage-Kinderhook Series	Lower Mississippian or Waverly Series	Pocono sandstone

In the Southern States, the lowest beds of the Mississippian are regarded as including the black *Chattanooga shales*, a remarkable and widespread series which are regarded as in some sense the equivalent of the lowest Mississippian farther

FIG. 267. Syncline in Carboniferous limestone. East side of Big Horn Mountains, Wyoming. A creek is here flowing in the syncline. This clearly looks like a settling of the foundations underneath, rather than a lateral compression. If the stratified deposits here are a mile or more in depth or thickness, it would not require very much of a settling (proportionately) to produce this result. (Darton, U. S. G. S.)

north. The Chattanooga black shales are so intimately interfingered with the various other beds to the north, both the Upper Devonian and the Lower Mississippian, that there is much dispute as to their exact relationships.

In the Great Plains and the Rocky Mountain regions, the other preceding systems of the Paleozoic group have been either entirely absent, or at the most but scantily represented. In contrast with this, the Carboniferous rocks are widely represented in these regions, and some of these rocks are found in places on the Pacific coast as far north as Alaska. As the other members of the Paleozoic are absent over these areas, or only a few of them are present, and that scantily, the Carboniferous throughout these parts is found to *rest upon the Pre-Cambrian,* or upon any other members of the Paleozoic which happen to be present, "sometimes in apparent conformity." (Scott.) Over the West and the Central States, limestones are the prevailing beds.

In the Rocky Mountain region, the limestones are known as the *Madison limestone,* the limestones (with some shales) in Southern Alberta which go under the name of the *Lower Banff series* being regarded as belonging to the same set of beds.

In the central interior, crinoidal limestones are chiefly found, nearly 400 species of crinoids having been found near Burlington, Iowa, alone. Brachiopods, such as *Productus* and *Spirifer,* are found in abundance along with the crinoids, with cup corals and bryozoans. The flat crushing teeth of cestraciont and cochliodont sharks, and also their sharp fin spines, are found also in these beds. "That reef-building corals were not present in this warm and clear sea is strange, since reefs were made at this time in Europe." (Schuchert.) If we could only dismiss this idea of a time-value as attaching to these beds, this difficulty, with many others, would vanish.

In New Brunswick and Nova Scotia, the Mississippian beds are represented by conglomerates, sandstones, shales, and great quantities of gypsum, with some dolomites. In Alaska, on the Arctic shore, are thick beds of coal, which are mined at Cape Lisburne. Some of the coal beds at this latter place are regarded as belonging to the Jurassic system.

Soft red sandy shales are found in Pennsylvania (*Mauch Chunk, Pottsville*), and are regarded as the equivalent of these marine deposits in the interior and the north.

Land vertebrates and fresh-water fishes are practically absent from the Mississippian rocks. In one of the subdivisions "is a dwarf fauna of more than seventy species which reappears at least four times, but is always connected with the same

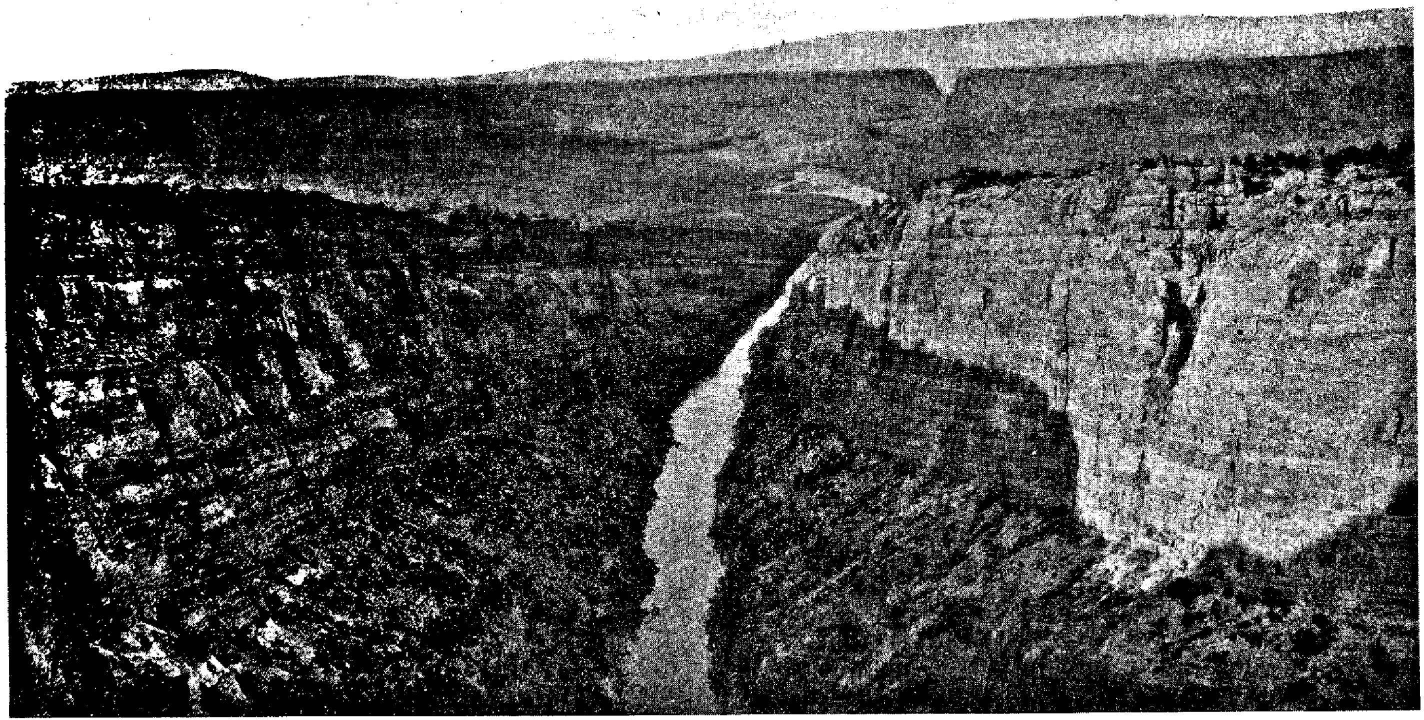


FIG. 268. North end of the cañon of the North Platte River, 4 miles south of Alcova, Wyoming. Looking north. Shows Tensleep sandstone (L. Carboniferous) dipping under "Red Valley" beds. Alcova Gap in the middle distance. (Darton, U. S. G. S.)

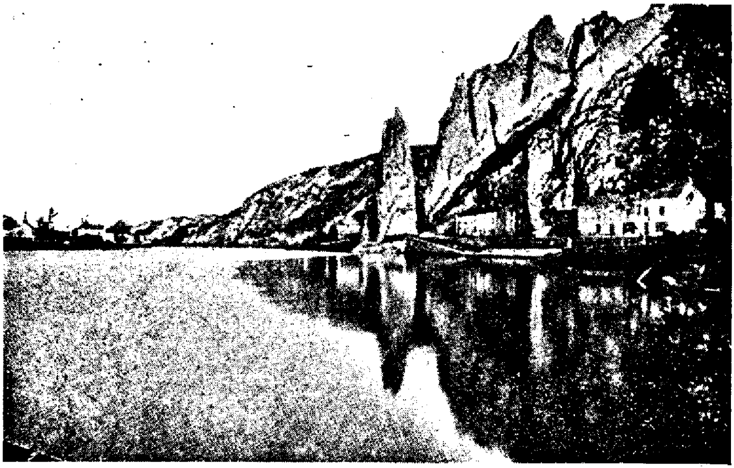


FIG. 269. Dinantian (Mississippian) limestones on the banks of the Meuse at Dinant, Belgium; the locality from which the name is derived. (After Haug.)

physical environment, shallow-water oölite deposits." (Schuchert.) This group of fossils is known as the *Spergen fauna,* being best shown at Spergen, Indiana. Associated with these other fossils is a single species of Foraminifera, and numerous blastids (*Pentremites*), which in places are so numerous that these beds have sometimes been called the Pentremital limestone.

In the Mauch Chunk beds of Pennsylvania are slabs marked with the tracks of amphibians and with rain imprints and ripple marks.

Pennsylvanian

Distribution. The Pennsylvanian rocks contain the great coal beds of America, England, Continental Europe, and China.

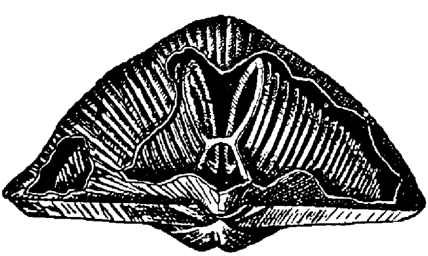


FIG. 270. *Spirifer striatus,* a Dinantian (Mississippian) brachiopod, with shell partly broken open to show the internal spiral arm-supports.

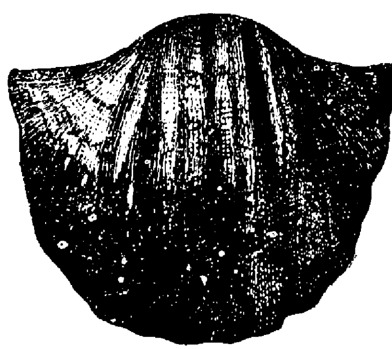


FIG. 271. *Productus giganteus,* one fourth natural size. Dinantian (Mississippian). (Kayser.)

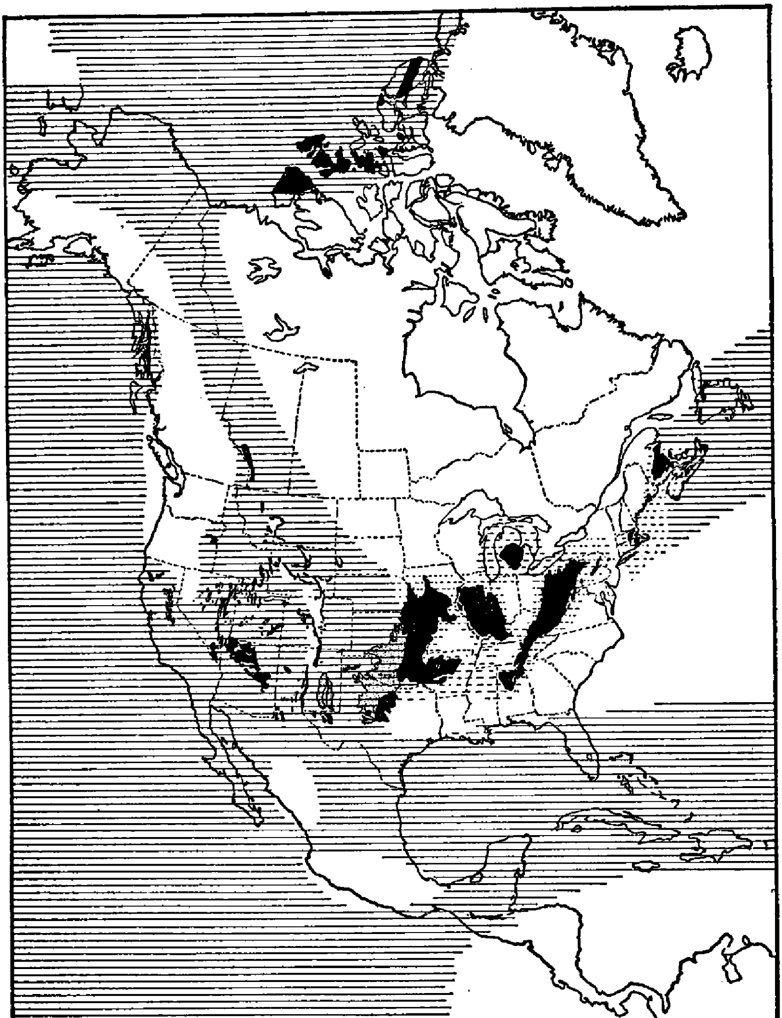


FIG. 272. Map showing the outcrops of Upper Carboniferous (Pennsylvanian) strata, indicated in black. The dotted area indicates the Permian of Kansas and Texas. (After W. B. Scott, "Introduction to Geology," permission of Macmillan Co.)

These coal beds are perhaps the most extensive coal deposits found anywhere, though many other geological systems, notably the Cretaceous, also have extensive coal deposits.

The *Pennsylvanian series*, consisting of marine deposits which alternate with coal or its associated beds, are found from Pennsylvania (with many interruptions) to Nebraska, Kansas, Oklahoma, and Texas. In the western part of this area, the coal beds are often associated with true marine fossils, and

frequently interbedded with calcareous shales and limestones. In the eastern part, the strata are coarser and much thicker, and consist of sandy shales and gritty sandstones, the marine calcareous beds being few or wanting. Here, too, the coal accumulations are the thickest, consisting of some of the richest and best coal beds in the world.

The lower beds of the Pennsylvanian series (*Pottsville*) show evidence of strong currents in their "repeated and pronounced torrential cross-bedding." (Grabau.) These coarse, cross-

FIG. 273. View along the strike of an outcrop of Mississippian limestone (U. Carboniferous), looking down the south fork of Sulphur Cañon, Idaho. The strata are dipping to the right. (Mansfield, U. S. G. S.)

bedded sandstones and conglomerates do not usually contain marine fossils, or, indeed, fossils of any kind, though there are occasional exceptions to this rule. Fossils are never well preserved in coarse sandstones or conglomerates.

The Coal Measures. The coal beds themselves are found in what seem like "a series of disconnected basinlike areas" (Grabau), though the interruption of these beds may have been due, in some cases, to subsequent erosion. In many instances, however, the beds were doubtless deposited in quite distinct basins. Throughout the area of the Coal Measures, there are great differences in the nature and in the thickness of the coal beds. "In one portion may occur a coal seam of great thickness,

divided into two or more layers by exceedingly thin 'partings' of shale. As we trace the coal seam in the proper direction, the partings gradually grow thicker, until, perhaps, they become strata, that intervene between very distinct and widely separated coal seams, each of which is continuous with the corresponding portion of the thick seam." (Scott.) It is hard to reconcile these facts with the swamp-bog theory of the origin of the coal.

The strata associated with the coal are mostly shales, sand-

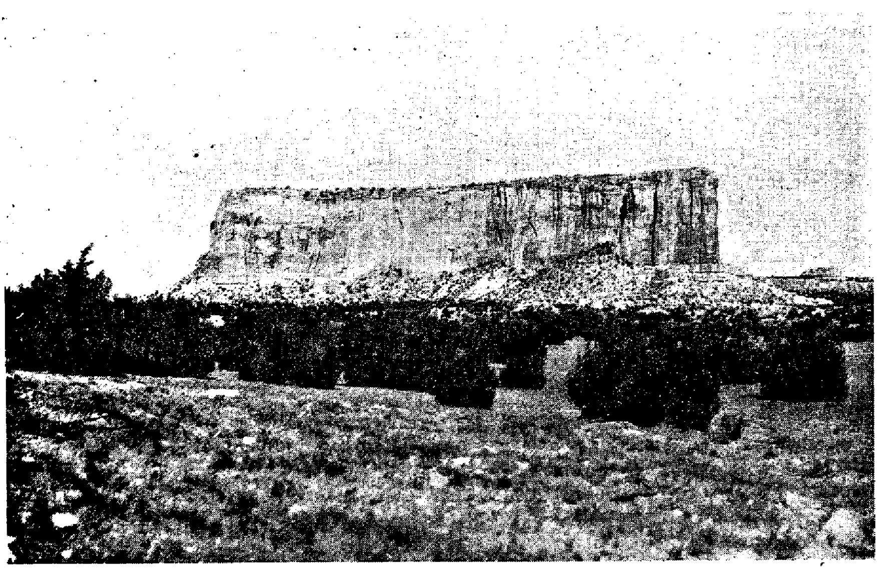


Fig. 274. Enchanted Mesa, near Acoma, New Mexico. Composed of Zuni sandstone (Pennsylvanian), with a thin cap of Dakota (?) sandstone (L. Cretaceous). The top of this mesa is over 400 feet above the plain. (Stanton, U. S. G. S.)

stones, and, in some places, limestones, the workable coal beds comprising only about 2 per cent of the entire Coal Measures. Many of the shales and other beds in between the coals proper are highly impregnated with carbonaceous matter, and are often black in color. Lumps or bowlders of coal-like masses are often found in the sandstones and other coarse materials interbedded with the coals, showing that the fossilization of the carbonaceous material was very quickly accomplished, or that isolated masses of vegetation were buried in addition to the regular deposits now forming the coal beds. *Pure coal beds are, in reality, very rare, as compared with the total amount of carbonaceous materials which are mixed up with sands and muds* (of course, in a hardened form).

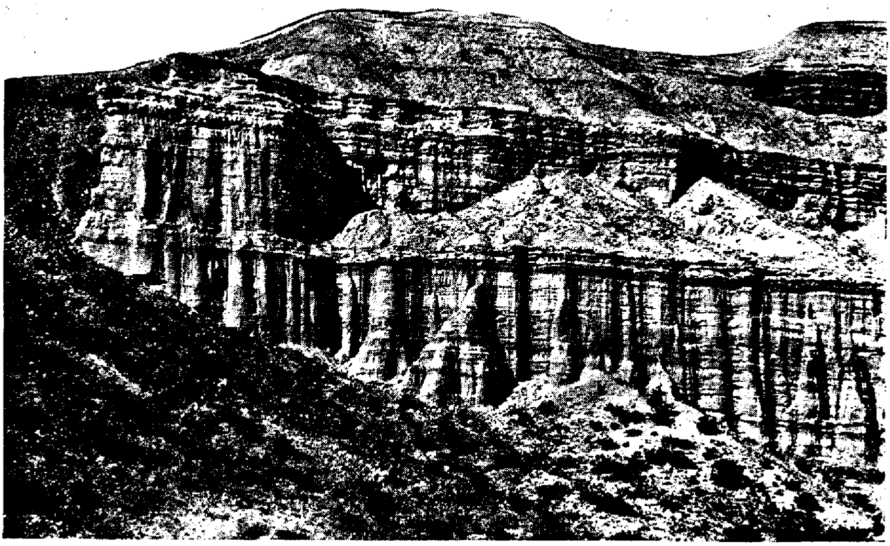


FIG. 275. Unconsolidated sand and gravel of the Rio Grande formation (Carboniferous), near Rincon, New Mexico. (Lee, U. S. G. S.)

Underlying a coal bed directly is often a bed of grayish or bluish shale, called by miners the *"seatstone,"* or *"underclay,"* which is formed by the chemical action of the various acids produced by the decomposition going on in the beds above, which have reacted on the sediments present in the underlying beds, removing the alkali materials from the feldspar, and converting it into a fire clay. When such an underclay is absent, as in Illinois, Nebraska, and elsewhere, the rock below is usually a sandstone or a shale. The layers capping the coal, especially if shaly, are often filled with fossil leaves and stems. In some cases, trunks of old trees rise and extend from the coal bed up through many feet of the overlying beds. In the Killingworth colliery, near Newcastle, England, one such fossil tree, with roots resting in a shale, was found to extend through ten distinct overlying strata. In Dulkeith, Scotland, the stem of a tree nearly two feet in diameter was found rising from the floor of the coal, passing through the coal bed itself, and entering the roof. Lyell mentions one tree, over 60 feet long, with a diameter at the base of five feet, which stood at an angle of about 40 degrees, and in-

tersected over ten distinct beds of the sandstone, these beds being "divided into laminæ so thin, that from six to fourteen of them might be reckoned in the thickness of an inch." This latter fact, which is of common occurrence, is a good indication that these coal deposits did not require the long ages of swamp-bog accumulation which are commonly assigned for their production.

It is supposed that the original bed of vegetable matter must have been 12 or 14 times as thick as the bed of coal is, hence we get some idea of the quantity of plant remains which it must have taken to produce the coal beds. The beds vary in thickness from a fraction of an inch to 30 or 40 feet, though eight or ten feet is a common thickness. Some parts of the famous Mammoth Vein, in the anthracite region of Pennsylvania, are 50 feet thick. It would be a conservative estimate to say that

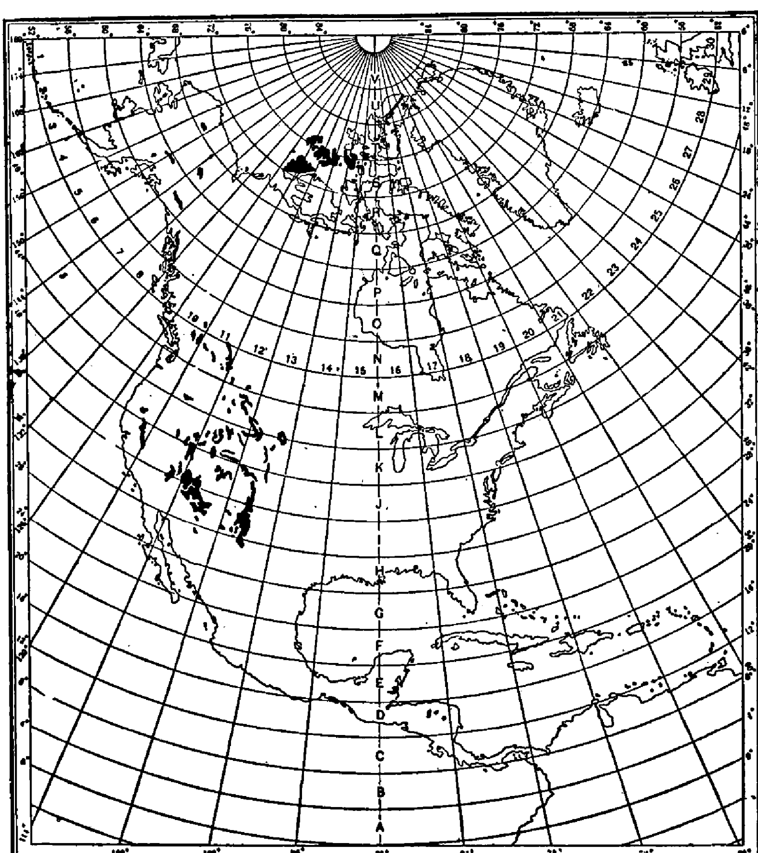


FIG. 276. Map showing the outcrops of the Carboniferous rocks of North America, which have not been subdivided into Mississippian and Pennsylvanian. (After Bailey Willis, U. S. G. S.)

this giant seam must represent a thickness of over 500 feet of pressed vegetable matter.

Other Characters. The method of formation of the coal beds will be discussed in a subsequent chapter; but here it should be noted that in some of the coal areas, there is found a *remarkable alternation* of coal beds with other kinds of rock. In the Joggins section, at the head of the Bay of Fundy, in Nova Scotia, there are some 76 of these successive beds; while in England and on the Continent of Europe, this number is much exceeded. But it is the usual thing to find the very same kinds of plants in the lower seams as in the upper ones; and the same kinds of shells and other animal fossils often occur in the upper shales and sandstones as in those associated with the lower beds. All of which is hard of reconcile with the immense lapse of time commonly associated with the production of these beds. This fact will be spoken of more particularly later.

Some coals contain much pyrite, or iron sulphide, which is an indication that sea water had access to the plant remains, hydrogen sulphide being generated by bacterial action only when sea water has been mixed with the decomposing vegetation. (Grabau, "Principles of Stratigraphy," pp. 493, 494.) Some of this sulphide is present in almost all coal, and is the chief source of the strong sulphur fumes given off from burning coal.

Beds of iron ore, often in the form of impure siderite (clay ironstone), are very common in the coal districts. They have been formed by the organic acids generated from the vegetable deposits, which have taken out the iron originally disseminated through the neighboring rocks, and have concentrated it in the form of iron carbonate. When mixed with more or less clay, it is called *clay ironstone;* and when it is found mixed with coal or carbonaceous matter, it is called *blackband ore,* which is a very valuable ore occurring in Ohio and Pennsylvania. The formation of these iron ores will be treated of more at length in the succeeding chapter.

Foreign

In England and Western Europe, the succession of strata in the Carboniferous is similar to that in the eastern part of North America; but in Russia, the Carboniferous is mostly marine, as in the western part of North America. The *Mountain Limestone* underlies the Coal Measures in Ireland, Western England, Belgium, and parts of Germany. In Scotland, these limestones are replaced by sandstones and impure coals. East of the Rhine, the similarly placed beds are mostly sandstones and shales, and are called *Culm.*

The *Culm* of Northern Europe and Asia is generally characterized by the presence of shales, sandstones, and conglomerates, the shales often holding plant remains. "A remarkable occurrence in this series is seen in beds rich in Radiolaria, which are suggestive of a deep-water origin for the formations, whereas the character and mode of occurrence of the other fossils, especially the plants, indicate shallow water." (Grabau, "Textbook," Part 2, p. 461.) The Radiolaria, it will be remembered, are now found only in the deeper waters of the Pacific and the Indian Ocean; and it certainly does look strange to see these specifically deep-sea forms mixed up in this way with land plants, or even with shales, sandstones, and conglomerates.

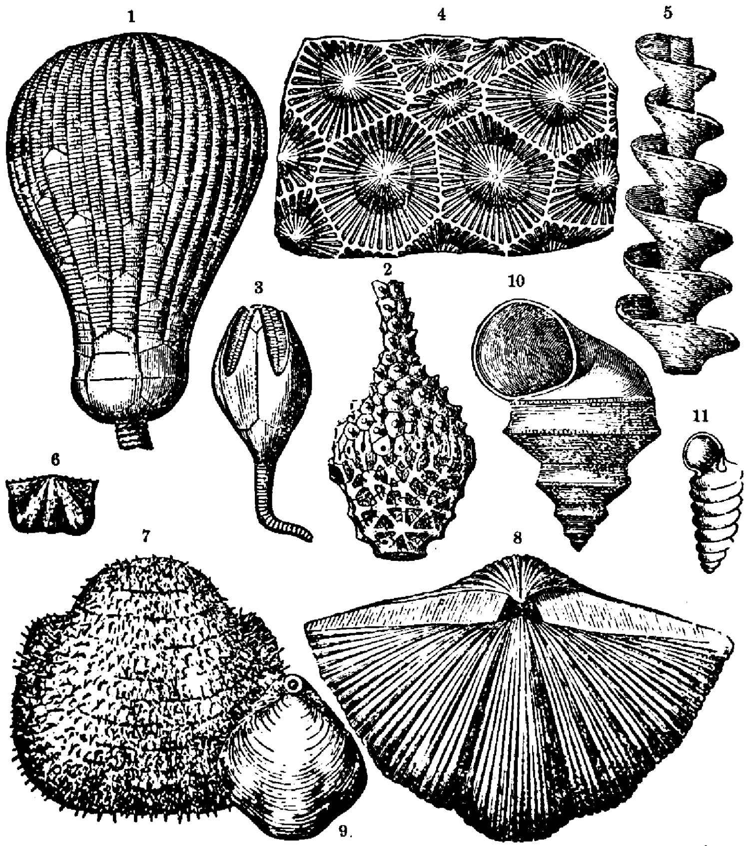
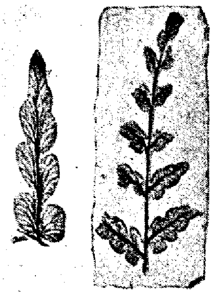
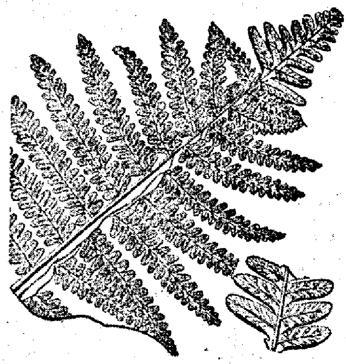


FIG. 277. CARBONIFEROUS FOSSILS

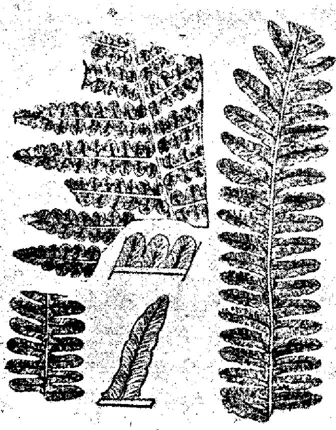
1, *Zeacrinus elegans*; 2, *Actinocrinus proboscidialis*; 3, *Pentremites pyriformis*; 4, *Lithostrotion canadense*; 5, *Archimedes reversa*; 6, *Chonetes mesoloba*; 7, *Productus rogersi*; 8, *Spirifer cameratus*; 9, *Athyris subtilita*; 10, *Pleurotomaria tabulata*; 11, *Pupa vetusta*. (After Dana.)



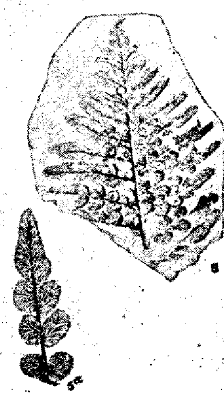
Carbonic fern, *Mariopteris pottsvillea*. Lower Pottsville. (After D. White.)



Carbonic fern, *Pecopteris vestita*. Coal measures, Pennsylvania. (After Lesquereux.)



Common Carbonic fern, *Alethopteris pennsylvanica*. (After Lesquereux.)



Neuropteris pocahontas. Lower Pottsville. (After D. White.)

FIG. 278. FOSSIL FERNS

The Culm type of Lower Carboniferous runs as far north as Spitzbergen; but in the south of Europe are limestones, with fossils much like those of England and Western Europe. They contain the well-known index fossil, the brachiopod, *Productus giganteus.*

"These beds can be traced south to Sarajevo in the Balkans, through Asia Minor, Persia, and the Kirghiz Steppe, through Central Asia north to the Tian Shan Mountains, through North China, and so on into the western part of the Cordilleran trough of North America, where the same *Productus giganteus* is found."— *Grabau, "Textbook," Part 2, pp. 461, 462.*

"In Russia the order of succession is reversed, the productive coal beds being below and the great bulk of the limestone above, but there is some productive coal interstratified in the marine limestones of the Donjetz basin in the south."—*Scott.*

The limestones thus found capping the Coal Measures in Russia and throughout great areas of Southern and Eastern Asia are largely composed of the shells of Foraminifera, the genus *Fusulina* predominating. These shells are identical with those largely composing the Carboniferous limestones of the western part of America, and extending as far east as the Mississippi River. Throughout Southern Europe, limestones and Culm are succeeded by the foraminiferal limestone and other clastic sediments, but without coal beds. The limestones of the Upper Carboniferous are found in Greenland, Spitzbergen, Bear Island, Nova Zembla, and other places in the arctic regions. Similar limestones, showing these same Foraminifera, are found in Japan, Borneo, and Sumatra; while in China, they are also accompanied by very extensive coal beds, the coal deposits of this country being among the richest of the world.

Carboniferous beds with plants like those of the Coal Measures of Europe are found near the east coast of Africa, in the Zambesi district; while limestones classed as Carboniferous occur in Egypt and Morocco, in the north of this continent. In South America, the Carboniferous beds are not so well developed as we have found the Devonian to be; but sandstones classed as Carboniferous are found in Argentina, containing plants similar to those of Africa and Australia. Carboniferous limestones also occur in various parts of South America.

Life

Plants. The plants of the Carboniferous system are much the same as those of the Devonian, though accumulations of vegetable matter are not found in the Devonian. Perhaps it would be more correct to say that if large beds of vegetable matter are found anywhere, they must be always classed as Carboniferous, and not as Devonian, though the plants are much the same in each. The limestones, shales, and sandstones of the Carboniferous "are so similar to the rocks of the Devonian and Silurian that they can not be distinguished except by the fossils." (Dana.) The fossil plants include over 1,000 species, and comprise ferns, lycopods, including *Lepidodendron* and *Sigillaria,* with *Equisetales* (horsetails), especially the genus *Cala-*

mites, the stems of which are among the most common fossils of the coal beds.

The *Cycadofilices* resembled the tree ferns of the tropics, and their remains are found in great abundance, probably also contributing much material for the formation of the coals. A group

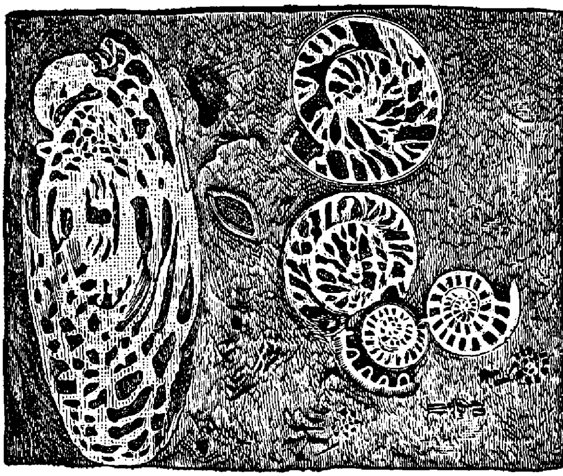


FIG. 279. *Fusulina* (× 9), polished slab of limestone showing shell in section. Carbonic.

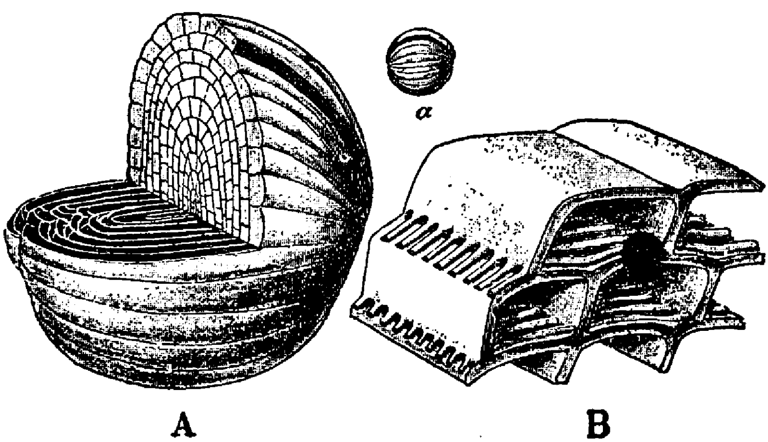


FIG. 279*a*. *Schwagerina verbecki*, Carbonic. *A*, diagrammatic view; *B*, plan of structure; *a*, natural size.

of gymnosperms called *Cordaiteæ* also occur, and they are supposed to be related to the existing orders of gymnosperms, the cycads, conifers, and gingkos. The exact facts regarding the kinds of plants found in the Coal Measures are not yet well understood.

These plants will be more fully described in a succeeding chapter dealing with the formation of the coal beds. Here we may call attention to the wide distribution and the uniform character of this assemblage of plants, which are included under the Carboniferous flora. "We find the same or nearly allied

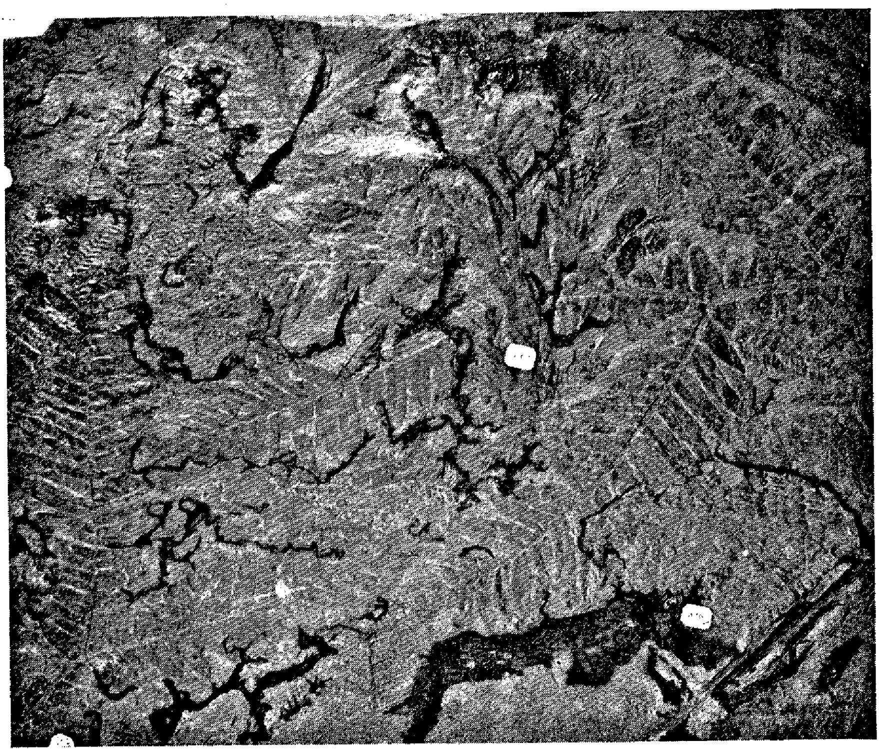


FIG. 280. *Neuropteris clarksoni*, Lx. High anthracite, Olyphant, Pennsylvania. (Hardin, U. S. G. S.)

species of plants spread over North America, Europe (even in the polar lands, like Spitzbergen and Nova Zembla), Siberia, China, the Sinai peninsula, Brazil, Australia, and Tasmania." (Scott.)

Deep-Sea Animals with the Coals. It is at least remarkable that the one-celled Foraminifera should be so widely associated with the coal beds, as these creatures are now almost exclusively found in the open ocean; their remains composing vast areas of the oozes at the bottom of the deeper parts of the Atlantic, the Pacific, and the Indian Ocean. Many living genera are represented among the widespread foraminiferal limestones of the Carboniferous, though the most numerous are *Fusulina,* a very

FIG. 281. Fossil fern, *Pseudopecopteris macilenta*, *Lepidocystis* (*Polysporia*) *salisburyi*, *Lx.* Pottsville (L. Carboniferous). The first specimen is from Arkansas, the other from Alabama. (Hardin, U. S. G. S.)

large kind, looking much like a grain of rice or of wheat. (Fig. 279.) It is said to be extinct. Another more globular genus, *Schwagerina* (Fig. 279*a*), is also present in these rocks which are so widely distributed over the larger part of the Old World and the western part of North America.

"Fossil Hickory Nuts." The *blastoids* constitute a group of extinct Echinodermata which are regarded as very characteristic of the Carboniferous limestones. They are used much as "index fossils," as it is considered that they became extinct with these Carboniferous rocks. In appearance, they resembled the closed bud of a flower, which is indeed called the *"calyx"* of the animal, for it also had a stem, like a crinoid. Their structure and habits are not at all understood, as they are entirely extinct, though they seem to have been related in structure to the crinoids and the sea urchins.

Crinoids. But the *crinoids* are by far the most numerous echinoderms of the Carboniferous rocks, more than 600 species having been described from the North American Carboniferous limestones. Several localities, as Burlington, Iowa, and Craw-

fordsville, Indiana, have become famous for the abundance and splendid preservation of their fossil crinoids.

"The crinoid remains occur in such multitudes that in many places the limestones are principally composed of them; in such places they must have covered the sea bottom like miniature forests."— *Scott.*

Sea Urchins. The *Echinoids*, or sea urchins, are common in these rocks; but they are all said to belong to genera which are extinct. However, when we understand the great variations exhibited by these animals, we are naturally inclined to question the accuracy of such a statement. Some of them were large; and at least one kind closely resembles the modern genus *Cidaris*.

Arthropods. Of the *Arthropoda*, the trilobites are rare; the eurypterids are common, though not so large as those found in the Devonian; while horseshoe crabs are also represented. Some of these animals are even found mixed up with the coal beds themselves. Centipedes, scorpions, and spiders are also found, with both neuropters and orthopters among the insects.

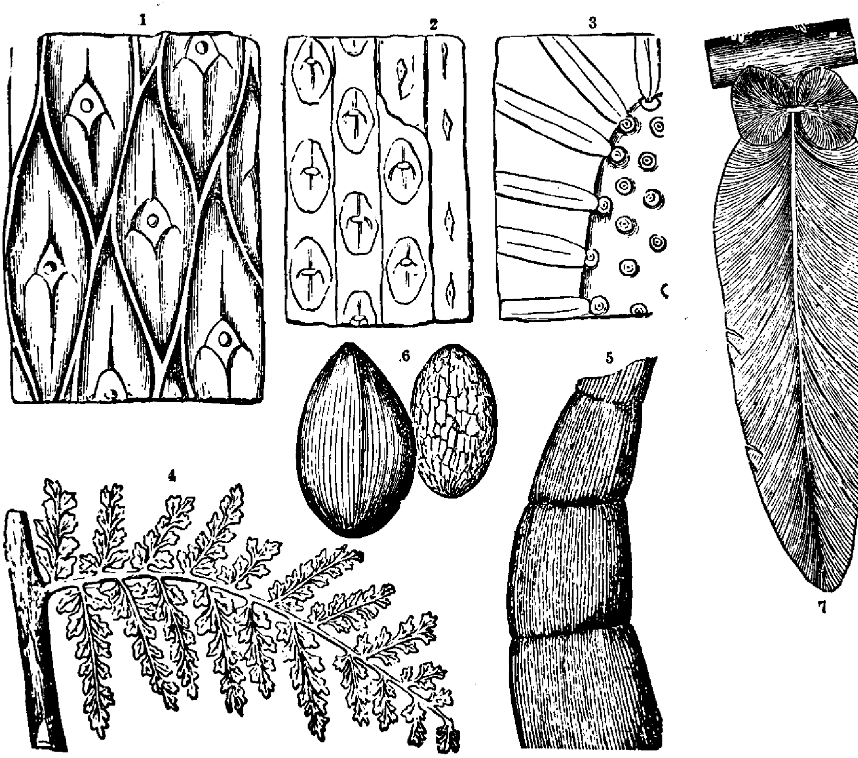


FIG. 282. Permo-Carboniferous plants. 1, *Lepidodendron obovatum*; 2, *Sigillaria oculata*; 3, *Stigmaria ficoides*; 4, *Sphenopteris gravenhorstii*; 5, *Calamites cannæformis*; 6, *Trigonocarpum tricuspidatum*. 4 and 7 are regarded as Permian. (After Dana.)

"Many of the Carboniferous insects are remarkable for their great size, some of them measuring 30 inches across the extended wings, and more remarkable is the fact that several insects of this period had three pairs of wings, corresponding to the number of legs."— *Scott.*

Brachiopods. *Brachiopods* are not so numerous or so varied as in some of the rocks already studied. But the genera *Spirifer* and *Rhynchonella* are well represented, and also *Dielasma,* quite similar to the genus *Terebratula,* which figures so largely in the Mesozoic rocks. But most important and most characteristic of the Carboniferous brachiopods is the great genus *Productus,* represented by many species, one of them, *P. giganteus,*

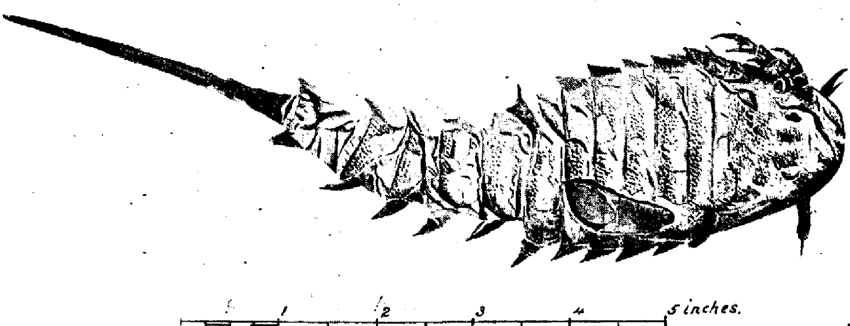


FIG. 283. *Eurypterus mansfieldi,* Hall. Specimen from just below Darlington cannel coal, near Cannelton, Pennsylvania. (U. S. G. S.)

being the largest brachiopod known. The larger valve of these forms is very convex, and often spinous; while the smaller valve is flat or even concave.

Mollusks. Of the *Mollusca,* the true bivalves are abundant, as are also the gastropods, the same genera being found in the Carboniferous as in the preceding Devonian and Silurian beds. Of these, *Pleurotomaria* was long thought to be extinct; but within modern times, five species have been discovered in the very deep waters of the West Indies and near Japan. *Orthoceras,* one of the nautiloid cephalopods, is also seen; but many other nautiloids are found in these rocks, their shells being ornamented with prominent ridges or tubercules.

Vertebrates. Sharks are quite common, even more so than in the Devonian; but the Dipnoi and the crossopterygians are not nearly so numerous. But the true ganoids (called variously *stylopterygians* and *actinopterygians*) are represented by sev-

eral genera, such as *Eurylepis, Palæoniscus, Eurynotus, Cheirodus,* and *Platysomus,* which are in appearance very much like modern fishes. They are said to be extinct.

Amphibians belonging to the extinct order *Stegocephalia,* shaped much like our modern salamanders, though some seven or eight feet long, are very common in the Carboniferous beds. Some, however, are much more elongated in form. Their skull was well covered with a roof of sculptured bones, the backbone was not ossified, the limbs were small and weak, the tail short and broad; and in many forms, the anterior portion was protected by an armor of bony scutes. A very large number of these Carboniferous amphibians are known. They were adapted for living amid the peculiar vegetation represented in the coal beds.

CHAPTER XXIX

The Permian System

Historical. The German miners used to have a series of red sandstones and limestones which they termed the *Zechstein.* Another associated series of magnesian limestones contained a black copper-bearing shale in their lower horizons, a series of great economic importance because of its copper ore. At a later date the Zechstein was found to contain the now famous Stassfurt salt beds. Afterwards these two groups were combined in one, to which was given the name *Dyas,* because of its two-fold character. The same beds (that is, their equivalents) were represented in England by the *Magnesium Limestone* of Dur-

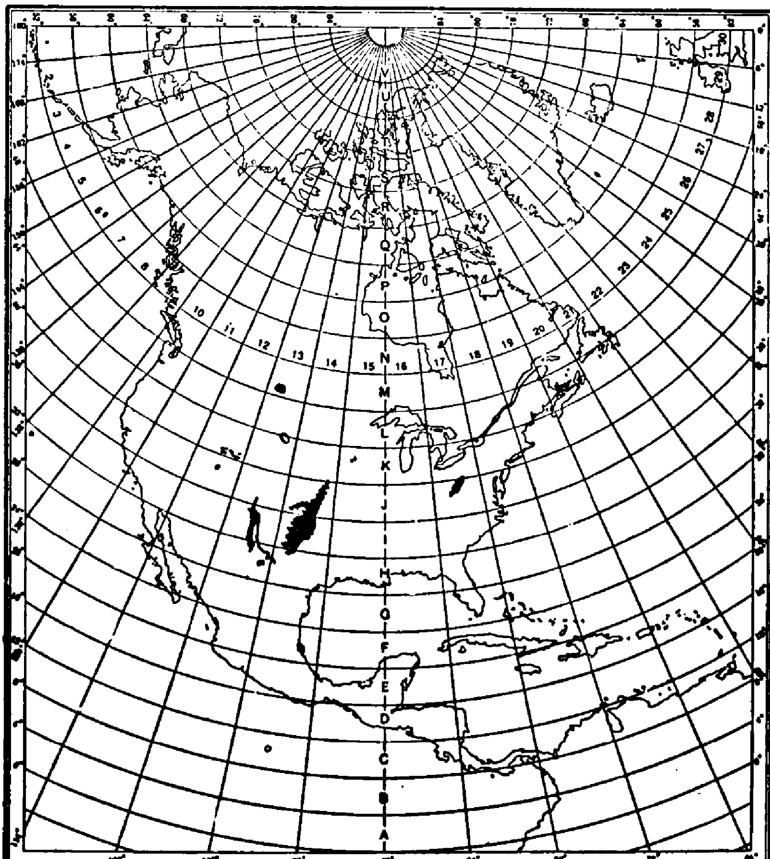


FIG. 284. Map showing the outcrops of the Permian rocks in North America. (After Bailey Willis, U. S. G. S.)

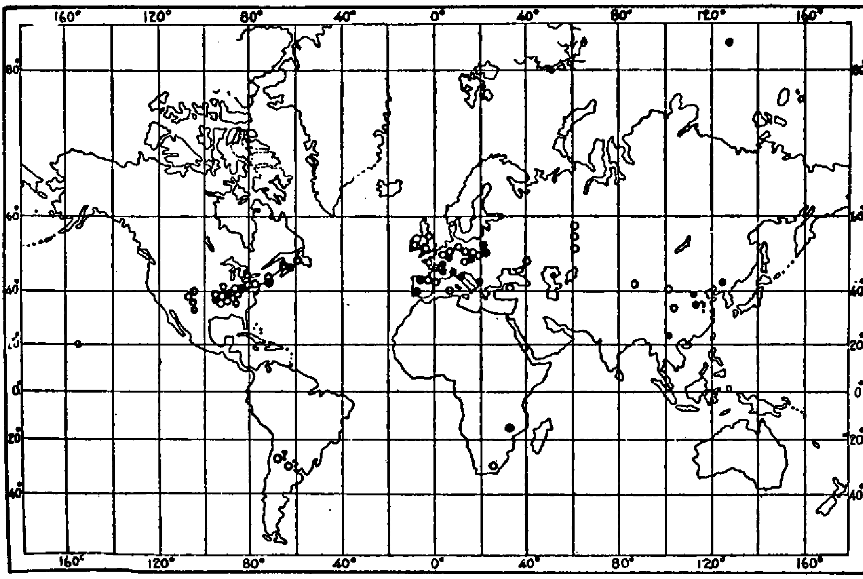


FIG. 285. Regional distribution of Pennsylvanian (U. Carboniferous) floras. White rings, Westphalian plants; black rings, Stephanian plants. (David White, U. S. G. S.)

ham, which, in the west of the island, was regarded as the lower part of what was called the *New Red Sandstone.* But as the result of Murchison's explorations in Russia, where this pioneer geologist found very similar strata in the province of Perm, near the Ural Mountains, the name *Permian* soon became recognized as applying to all these formations.

In the early days of geology in America, when little of the continent had been examined except the part near the Atlantic, it was thought that the Permian rocks were so scanty as hardly to warrant a separate system to include them; and so the custom was adopted of including them along with the Coal Measures, in a *Permo-Carboniferous system.* More recently, however, large areas of Permian rocks have been found in Kansas, Idaho, Wyoming, and Utah; and now the Permian system has won a recognized place in American geology.

Distribution. Soft red shales and sandstones, classed as Permian, are found extensively in Prince Edward Island, Nova Scotia, and New Brunswick, lying apparently above the Coal Measures. In Maryland, West Virginia, Ohio, and Pennsylvania, similar beds consisting of sandstones and shales, with a few seams of coal and some limestones, used to be called the *Upper Barren Measures;* but they are now classed as Permian because of the character of the plants which they contain. No Permian rocks have been found south of West Virginia; but

they have been described from Illinois and in the extensive regions of the West, as already mentioned.

When the Permian rocks of the West, in Kansas, Nebraska, and Texas, became known, it was declared by geologists that only the lower part of the Permian is represented by the beds in the Maritime Provinces and in the Atlantic States; the rest of the system finds better expression in these wide areas west of the Mississippi.

In Kansas, the beds consist of fine red clays, with some sandstone, conglomerate, and some impure limestone, in the north of the State, but with purer marine limestones in the southern part. Extensive salt beds are found interbedded with gypsum, but without sufficient fossils to make the identification of these beds quite certain. Sandy shales, also associated with gypsum, are traced through many parts of Northern Arizona and Southern Utah, Western Colorado, and Central Wyoming, where they are locally called the *Red Beds*. "The Red Beds are not all Permian, however, and the rarity of fossils in them makes it often impossible to decide whether a given area of these beds should be referred to the Permian, to the subsequent Triassic, or to both." (Scott.)

In the mountainous part of Western Texas, extensive Permian marine beds are found which contain fossils much like

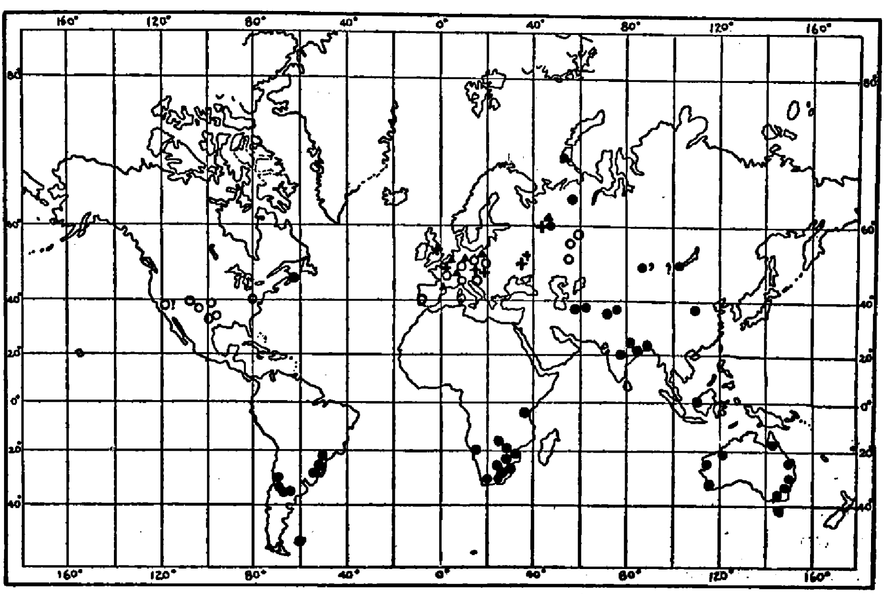


FIG. 286. Regional distribution of Permian floras. White rings, Lower Permian; triangles, Middle Permian; crosses, Upper Permian; solid rings, Gondwana flora. (David White, U. S. G. S.)

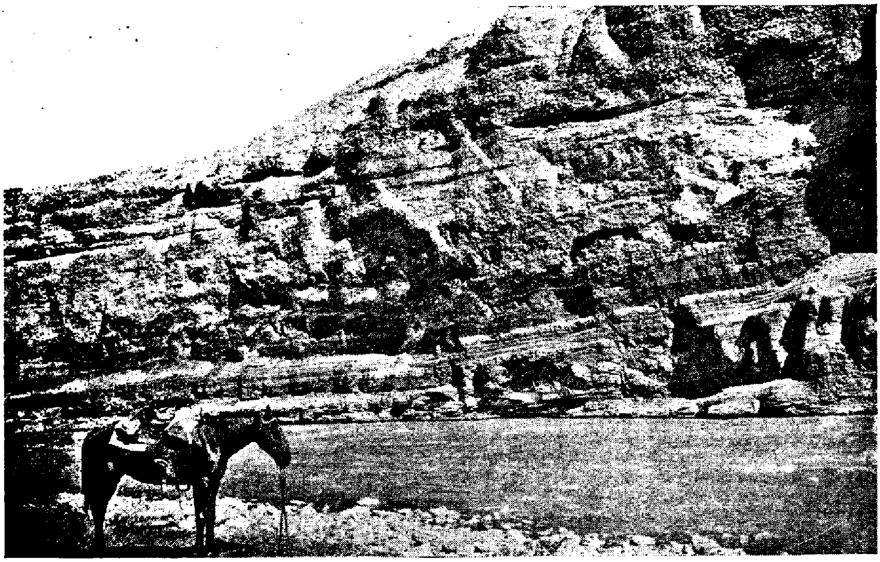


FIG. 287. Chugwater shales (Permian-Jurassic), capped by travertine cemented gravels. On the south bank of Shoshone River Cañon, at Hot Springs, above Cody, Wyoming. (Condit, U. S. G. S.)

those of the Mediterranean and of India. These Permian beds of Texas extend (with interruptions) across southwesterly through Mexico; and similar beds occur on the Copper River in Alaska, with traces of them in the Klamath Mountains of Northern California.

Foreign. In England and Central Germany, the sandstones, shales, and marls of the Permian are predominantly *red*, which has suggested to some that these beds were deposited in an arid climate, the gypsum and the rock salt, with extensive layers of potassium and magnesium salts, encouraging this explanation. On the other hand, the associated coal beds, which are found in this system not only in Central Germany, but also in France and Bohemia, on either side of these gypsum and salt beds, are good testimony against this hypothesis. Grabau is of the opinion that these red beds were light yellow or ochery in color when first deposited, but that they underwent a process of dehydration after being buried, just as yellow clay is very easily changed into a red brick by heating, the driving off of the water of crystallization contained in the yellow iron oxide changing the color to that of the red iron oxide, or hematite. ("Textbook," Part 2, p. 509.)

These Permian beds are very widely scattered throughout Central Europe, from Commentry, in Central France, to Silesia.

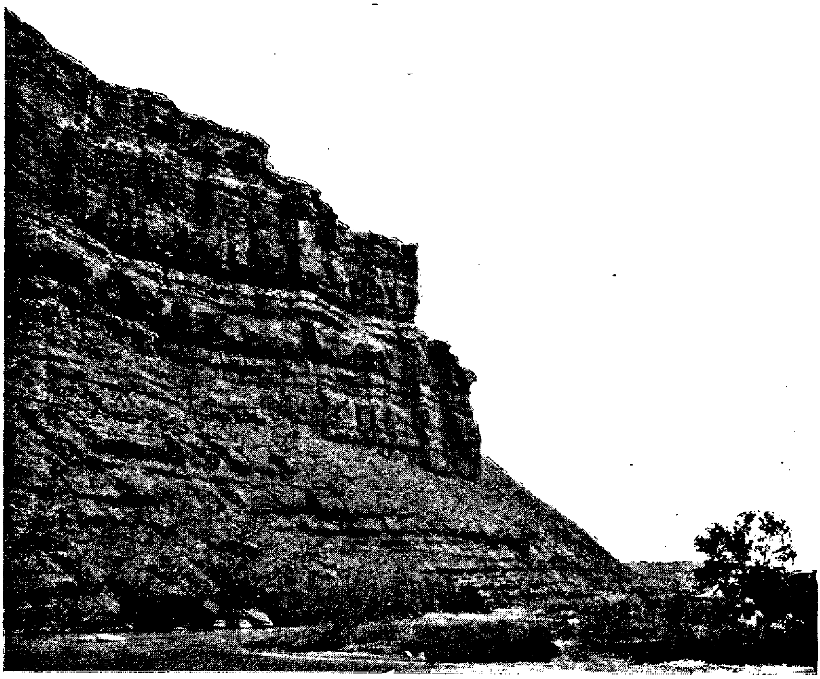


FIG. 288. Cliff of red beds of Chugwater formation (Permian-Jurassic), on No-Wood Creek, Big Horn Mountains, Wyoming. (Darton, U. S. G. S.)

They compose the older red strata of the Vosges Mountains, "and in the dry moat of the ancient Heidelberg Castle on the Rhine they can be seen to *lie directly upon the granite.*" (Grabau.) (Fig. 291.) Throughout Europe, many volcanic beds are classed with these Permian ones, these volcanics being scattered through Great Britain, France, and Germany, and also in some parts of the Alps; but this only means that these volcanic beds lie directly upon these Permian strata.

In Russia, the Permian beds extend along the Baltic coast and in a long strip along the west of the Ural Mountains to the Arctic Sea, and into Nova Zembla and Spitzbergen. Some of these beds greatly resemble the Permian of Kansas, and the fossils of associated beds in Russia and the arctic are like those of South Africa and other parts of the Southern Hemisphere, as will be given in more detail presently.

Permian rocks extend, of course with wide interruptions, from the Mediterranean eastward through Armenia, Persia,

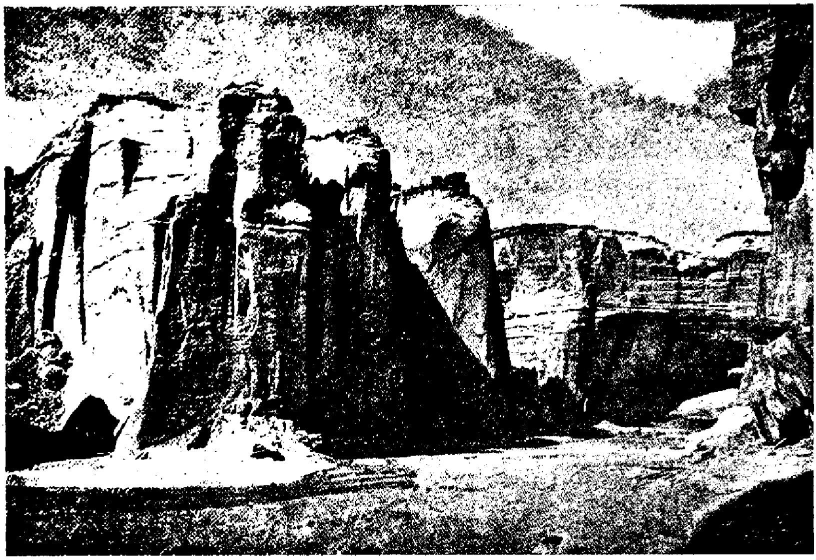


FIG. 289. Permian sandstone, 700 feet thick, Cañon de Chelly, Arizona. (From Mendenhall and Gregory, U. S. G. S.)

Tibet, China, and the island of Timor. In Northern India, the Permian compose a part of the remarkable *Gondwana series,* the rest being Triassic and Jurassic.

FIG. 290. Upper Bryozoan limestone, Park City formation (Permian), Popo Agie River, Wyoming. (Condit, U. S. G. S.)

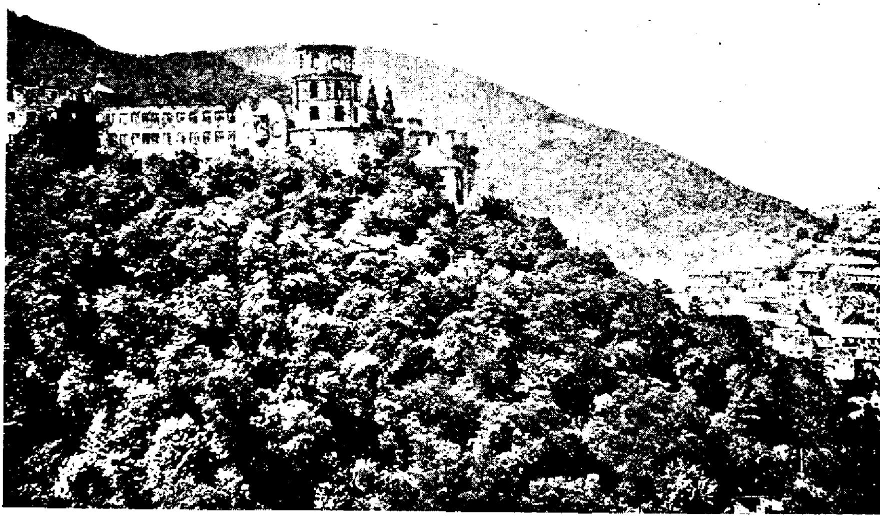


FIG. 291. Heidelberg Castle, Germany.

"Tillites." A coarse angular conglomerate with a so-called bowlder clay is found in these beds of extensive spread in Northern and Central India, while smoothed and striated pavement rocks have also encouraged the idea that these formations are of true glacial origin. But the associated floras and faunas do not give any encouragement to this idea; while it is always well to remember that it does not require huge glaciers to produce the phenomena which we have mentioned. As Scott remarks, "It is certainly very remarkable to find glacial deposits formed on such a scale within the tropics, and evidently at no great height above the sea level." An additional absurdity is introduced into the situation by the recent discovery that the movement of these hypothetical glaciers "seems to have been from the south northward, or *away from the equatorial region of to-day.*" (Grabau, "Textbook," Part 2, p. 521.)

An exactly similar situation has been discovered in South Africa, in what is known as the Karoo series. "Tillites" resting upon striated and polished older rocks are extensively spread out through Cape Colony, Transvaal, Rhodesia, and north to Nyasaland. In parts of these areas, the underlying smoothed and striated pavement is in "a state of wonderful freshness" (Scott), as if these deposits had been made in recent times.

This district is partly within the tropics; but here, as in India, the movement of these materials, with the scratches on the rocks, is *away from the equator toward the colder region.* Is it reasonable to think that huge glaciers once spread poleward in each direction from the tropics as a center?

The characteristic plants in the beds above the "tillites" are *Glossopteris* and *Gangamopteris,* accompanied by *Neuropteris* and *Sigillaria,* and also by reptiles and amphibians, practically the same kinds of plants and animals being found in scattered localities over nearly half of the globe, though mostly south of the equator. Coal beds with similar fossils are found in New South Wales and in other parts of Australasia, where the so-called glacial beds are interstratified with marine strata, some of the "tillites" themselves containing typical marine fossils. (Scott.) Permian beds containing the typical *Glossopteris flora,* as it is called, occur also in Argentina and Brazil.

Life

Plants. We have already seen the twofold character of the Permian in many parts of the world, this system being called the Dyas in Central Europe because of this dual character. This duality is especially marked in respect to the floras of these beds, the Lower Permian flora resembling the Carboniferous and the other Paleozoic formations, while the Upper Permain

FIG. 292. Section of the Dwyka bowlder clay at Prieska, northwestern part of Cape Colony, Africa. (After Hatch and Corstorphine, "Geology of South Africa.")

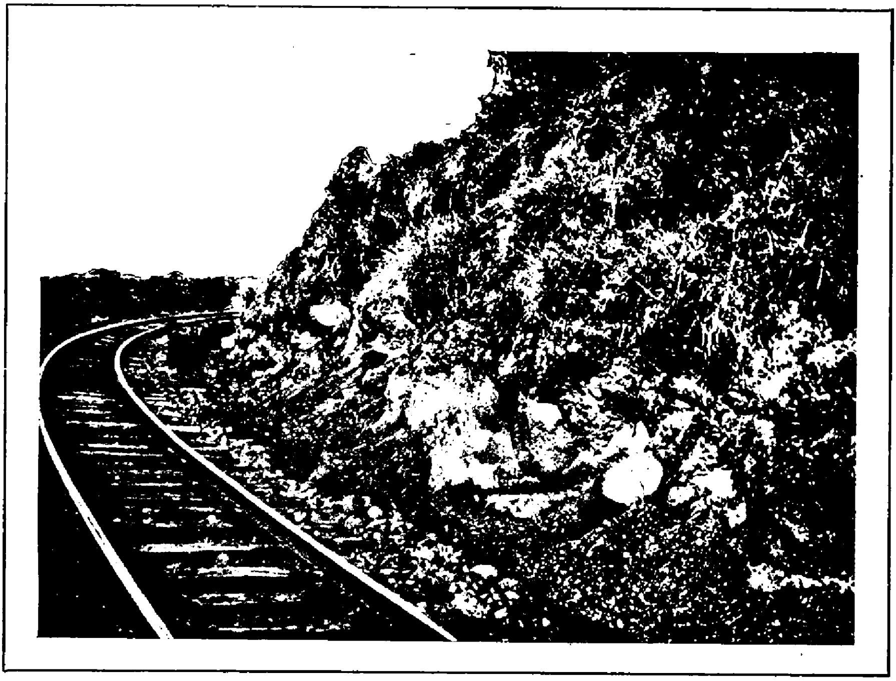


FIG. 293. So-called "tillite," or glacier-formed deposits, in Permian strata, State of Sao Paulo, Brazil. On the Mogyara Railway, between the stations Coronel Correa and Baldeacao. As this is within the tropics, it is difficult to believe that this area was once covered with a vast ice sheet. Would it not be more reasonable to seek some other explanation of these beds? (From Bulletin of the Geological Society of America, Vol. 30, 1918, pl. 10. Dr. G. Florence, photograph.)

flora is much more like that of the Mesozoic; "so that if the line dividing these two great eras [groups] were drawn in accordance with the vegetation, it would pass through the Permian." (Scott.)

However, the giant lycopods, *Lepidodendron* and *Sigillaria*, are not at all common in even the Lower Permian beds, though calamites and ferns are quite plentiful, tree ferns being even more common than in most of the Carboniferous. The Upper Permian flora is composed chiefly of ferns, cycads, conifers, and gingkos. The broad-leaved ferns, *Glossopteris* and *Gangamopteris*, with some associated ferns, conifers, and calamites, help to compose the almost cosmopolitan Glossopteris flora, though the extension of this flora into Northern Russia is associated with the Triassic rocks. This group of plants is also called the *Gondwana flora*, "Gondwana" being an imaginary continent in the Southern Hemisphere which by some geologists is thought to have united India, South Africa, Australia, and South America.

Invertebrates. Of the fossil animals, *foraminifers* are very widely scattered through the Permian rocks, and some corals belonging to the living *Hexacoralla* are found. But the crinoids are rare, and trilobites and eurypterids are found only as stragglers. Insects are very plentiful in some of these strata, some of them being very large.

Brachiopods are numerous, though few of them are distinctive of the Permian beds. But many characteristic molluscan bivalves appear, while the cephalopods are especially varied and abundant. Not only do we find many new species of the genus *Nautilus,* but many new ammonoids with very complicated sutures are particularly characteristic of these beds, some of the same species of ammonoids having been identified in the rocks of such widely scattered localities as Texas, Russia, Sicily, and India. Similar ammonoids are very common in the subsequent Mesozoic group.

Vertebrates. Many of the *fishes* are like those already spoken of from the preceding systems. But of the Dipnoi, the genus *Ceratodus,* similar to the living lungfish of Australia, occurs in the Permian beds. The teeth and fin spines of sharks are common.

Amphibians are very numerous and varied. Some were slender and snakelike, others were much like salamanders, while still others were shaped almost like alligators, with large, pe-

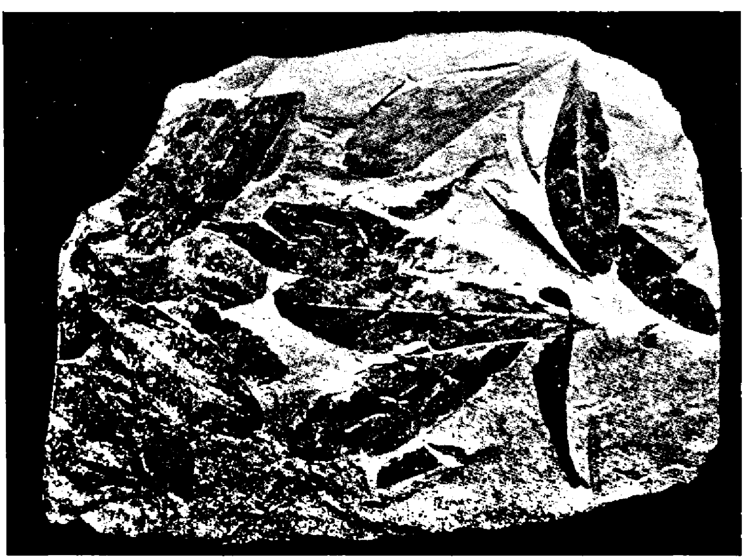


FIG. 294. *Glossopteris browniana,* Brngn. From Newcastle, Australia.

culiar heads. They ranged in size from a few inches up to eight feet. The *Stegocephalia,* called also *labyrinthodonts* because of their complicated tooth pattern, are especially characteristic of these deposits.

Many distinct kinds of true reptiles also are found, some of them in large numbers. They occur in a great variety of forms

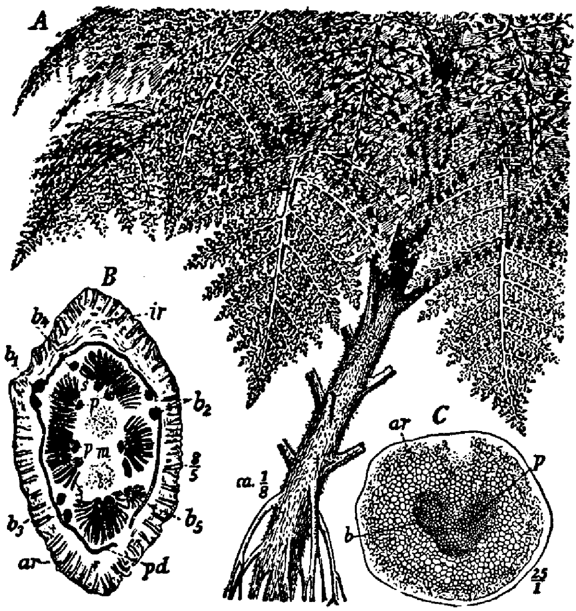


FIG. 295. A flowering fern (cycad fern) of the Upper Carbonic of England. (*Lyginopteris* [*Lyginodendron*] *oldhami.*) *A,* reconstruction of the plant about one eighth natural size, showing stem, aërial roots, sterile and fertile fronds; *B,* section of stem: *m,* marrow; *p,* primary wood bundles; *s,* secondary wood; *pd,* periderm, marking outer border of central cylinder; *ir,* inner bark; *ar,* outer bark, with radial bands of sclerenchyma; *b*1-*b*5, leaf bundles; *b*1 of oldest leaf, × 8/5; *C,* cross section of stem of frond: *p,* primary wood strands of V-shaped form, surrounded by a ring of bast (*b*); *ar,* outer bark, × 25. (After Steinmann.)

in the *Karoo* formation, South Africa, some of them being most bizarre in appearance, with a great row of high spines along the backbone, or with other strange characteristics. One group of these, the *theriodonts,* had a set of complete teeth, differentiated, as in the mammals, into incisors, canines, and multicuspid molars. Evolutionists naturally think this is a very good start from which to derive the teeth equipment of the mammals.

But this sudden appearance of a great variety of true reptiles in these Permian beds is a cause of some astonishment to those who explain all organic forms in terms of progressive evolution. The following is a typical remark along this line:

"There is no reason to suppose that such a variegated reptilian fauna can have come into existence suddenly, and their ancestors will doubtless be discovered in the Carboniferous [would these beds be called Carboniferous, if many such reptiles were to be found in them? G. McC. P.]; but while no true reptiles are certainly known from the latter, in the Permian they are the most conspicuous elements of vertebrate life." —*Scott, "Introduction to Geology," p. 652.*

But how simple the whole matter becomes when we understand that in all these geological distinctions and classifications, we are merely dealing with *zoölogical taxonomy,* or the zoölogical classifications of the ancient life of the world, and that these classifications are just as truly artificial as any modern taxonomic classification! These geological classifications have absolutely no more time-value than have the modern ones.

CHAPTER XXX

Coal: Its Occurrence and Origin

General Remarks. "Although many thousands of men," says Professor Suess, "work day and night in our Coal Measures, and although many acute observers are led by their profession to make the study of these deposits the business of their life, yet the mode of formation of the coal beds is still far from being satisfactorily explained." ("Face of the Earth," Vol. 2, p. 244.)

These words seem like a quite unpromising introduction to our subject; yet we shall do the best we can to present a rational and satisfactory explanation of the origin of the coal deposits. But first we must note the occurrence of coal and some of its characteristics.

Almost all the geological systems of rocks contain coal beds of some description; but the most important beds occur in the Carboniferous, the Cretaceous, and the Tertiary. Of these, the Carboniferous is the most important, and has been estimated to include seven tenths of the total coal beds of the world. In North America, the Carboniferous coals are east of the 100th meridian, the Tertiary are mostly west of the 120th meridian, with the Cretaceous beds in between. In Europe, the coal in the British Isles is chiefly Carboniferous, as are also some of the coal beds on the Continent; but the immensely thick brown coal beds of Germany, from 75 to 150 feet thick, are classed as Tertiary. Beds of brown coal even much thicker than this are known in Australia. China has very extensive coal beds; but they are mostly Carboniferous.

As will appear later, the distinction between these different geological systems is based on the kinds of fossils associated with the beds, and it is a common impression that only in the Carboniferous strata do we find good coal. But this is a mistake. Splendid anthracite, as good as any in Pennsylvania or Wales, occurs in the Cretaceous formations of British Columbia and Alberta, or even in the Tertiary beds there and elsewhere. But in a general way, it may be stated that the Carboniferous coals are more likely to be anthracite or bituminous, while those of the Cretaceous and Tertiary are more likely to be less carbonized, or even to be little more than pressed wood, as is the case with so many of the lignites. The latter usually occur at the surface of the ground, or close beneath the surface; while the

Carboniferous beds are sometimes many thousands of feet down. This makes an immense difference in the amount of pressure which these formations have been subjected to; and this difference in pressure, together with differences in the heat and other metamorphic agencies to which they were subjected, will partly account for the differences in the coals as we find

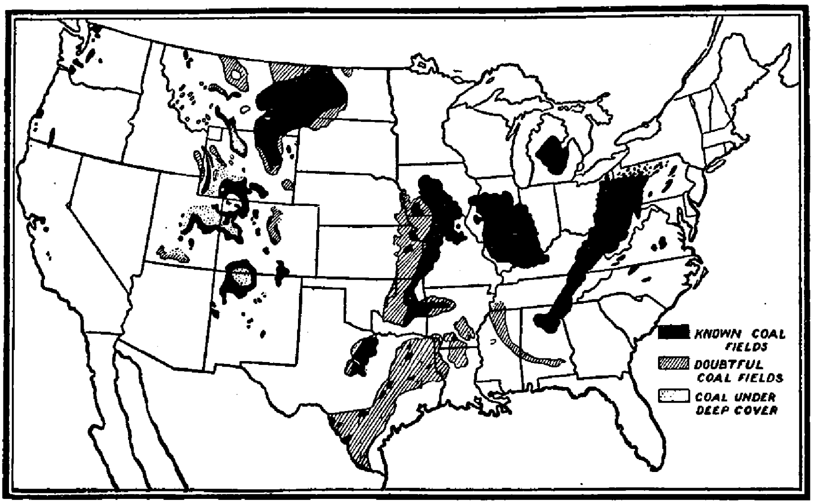


FIG. 296. Map showing general distribution of coal fields in the United States. (U. S. G. S.)

them. Yet it may be that the original differences in the plant materials entering into the beds may be largely responsible for the distinctions which we now observe.

Mineral Matter. In every coal region, there are always many very thin seams which are worthless as a source of coal, and also many seams of shale which are so impregnated with carbonaceous matter that they can be made to burn, though with a large amount of residue as *ash.* Good coals show only from 5 to 1 per cent of ash, but the percentage often runs higher. This ash is due to earthy or rock materials which are mixed up with the coal, having been included in the deposit when it was first made. Probably all the original plant remains, when first buried, contained much mineral matter; but in many of the larger or thicker seams, most of this mineral matter has been dissolved and leached out by the acids generated in the fermenting and decomposing mass, as will be explained later. The wonder is that so much of the coal is so nearly free from mineral matter.

Color of the Associated Strata. Red or yellow rocks are usually absent in the coal regions, because of the acids generated by the organic deposits, which dissolve the iron oxides which cause these bright colors. A similar explanation is made of the so-called "underclay" which is often found at the base of a coal bed. This is a *fire clay;* that is, it has lost the basic or alkaline materials which would act as fluxes and cause it to melt easily, so that now it is almost infusible, and can be used as the lining for blast furnaces, and in other places where intense heat must be resisted. It is often gray or almost pure white for several inches or even for several feet below the coal, and has been produced by the carbonic acid and other acids which formed in the decomposing mass of plant remains, these acids dissolving and carrying away, first the alkali material in the feldspar, and next the iron compounds, until the blanching is often complete throughout a thick bed. The great quantities of carbonic acid generated in these plant deposits will also serve to account for the very frequent occurrence of siderite, or iron carbonate, in association with the coal beds. Beds of iron carbonate several feet thick often alternate with the coal beds, being repeated many times in a vertical section. These beds of iron ore are also frequently found resting upon a pure fire clay, just as the coal does.

It is often stated that this "underclay" contains the remains of the roots of the plants (trees) which grew in the beds above, and that in many instances, the stumps of these trees are still found *in situ,* as they grew. It is curious how this assertion has been repeated over and over again in all the textbooks, being copied from one to another for more than half a century. However, the fact is that, while stumps are often found in the coal beds, it is only by the help of the imagination that anything like true roots can be detected as attached to them. As for the frequent assertion that the small rootlets can be still made out in the underclay, being derived from the plants which grew above, it is wholly imaginary. Of course, even if the vegetable matter were washed into the position of these beds and buried, the trees would in many instances carry their stumps and roots with them, and if the stem were broken off a few feet above the roots, the stump would in most cases sit upright, as is so frequently seen in snags in the rivers which have been floated down by floods or freshets; and many roots are always attached to the stumps in such instances. It may be confidently affirmed that there is no well-authenticated case where the presence of such old stumps in the coal beds can be proved to have been due unquestionably to growth on the spot. The wish is father to the thought in such reports.

Classes of Coals. There are four leading types of coal,—brown coal, lignite, bituminous, and anthracite.

Brown coal is little more than a compacted mass of plant remains, and is usually more or less of a homogeneous character

throughout. It may vary in color from a light yellow to a deep brown; but ordinarily not much can be determined regarding the kind of plant materials entering into its formation. Only in rare instances can anything like a positive identification of a particular type of plant be made; but if we suppose that the materials in the coal itself were similar to the plant remains preserved often with such exquisite perfection in the shales above the coal, we shall have no trouble in fixing upon the kinds of plants entering into the composition of these coals.

FIG. 297. General view of a lignite mine (Tertiary) about 12 miles south of Cologne, Germany. The lignite bed is from 25 to 30 feet thick, and is covered with 12 to 18 feet of sand and gravel. This is what is called the "open system" of mining. (Holmes, U. S. G. S.)

The brown coals burn with a sooty flame, a strong odor, and but little heat. They generally run from 55 per cent to 75 per cent of carbon. In density, they range from 0.5 to 1.5. Many of the Tertiary formations contain brown coal, the beds often being of an astonishing thickness; and these beds often occur near the surface.

Lignite is the name given to coal which has been made chiefly out of trees, such as conifers, and which has been only partially converted into coal. Often the texture of the wood can be distinctly made out. Lignites are common throughout the Mesozoic and the Tertiary formations. A regular grada-

tion can be traced from the little altered lignites to the true bituminous coals and the anthracites. It even occurs that a seam will be a lignite in one locality, and if followed up only a few hundred feet, will turn into a true coal, and perhaps even into a true anthracite, the change being due to some local source of heat, such as a dike.[1]

The ordinary soft coal is termed *bituminous*. It is black in color, of a bright luster, and quite brittle. Usually it runs from 75 to 90 per cent in carbon, and contains a greater or less amount of sulphur. In density, it ranges from 1.2 to 1.35. It burns with a clear flame; though there is a great diversity among the different varieties with respect to their behavior in the fire.

Under the microscope, the organic structure can occasionally be seen; and the kinds of plants contributing to its formation can almost always be recognized from the well-preserved leaves in the shales capping the coal bed.

Anthracite is the purest hard coal, and contains over 90 per cent carbon. It has a vitreous or submetallic luster, and breaks with a conchoidal fracture. Its density is from 1.35 to 1.7. It is difficult to ignite; but when once raised to a sufficient temperature, it burns with an intense, steady heat, without smoke or odor. Many anthracites are found in regions where the rocks have been disturbed; so they are commonly spoken of as metamorphosed bituminous coals. It is usually more difficult to make out the kinds of plants in the beds above the anthracites, as all traces of leaves have generally disappeared in the metamorphism which has accompanied the transformation of the coal. However, occasionally perfect leaves or other parts of plants have been discovered, so that we know with reasonable accuracy the kinds of plants contributing to these formations.

The Peat-Bog Theory. We must now consider briefly the problem of how the coal beds were probably formed; that is, how the plant remains were accumulated which were subsequently converted into the coal.

For nearly a century, we have been pointed to the peat bogs of the cool temperate regions as the nearest approach to the present formation of a coal deposit. We have already considered the growth and character of these peat bogs. They are

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[1] "Wood will also under certain circumstances pass into the state of lignite very rapidly, as may be sometimes seen in the timbers of old colliery workings. Count Solms-Laubach states that in one mine timbers 150 years old were found to be converted into lignites of black color, and lustrous conchoidal fracture, while in another case as little as six years was necessary to produce similar changes."— *E. A. Newell Arber, "The Natural History of Coal," pp. 65, 66; Cambridge University Press.*

confined to cool climates; no such deposits exist in the tropics. Hence, as all the coal deposits found in our fossiliferous formations were certainly produced under tropical or semitropical conditions, the mangrove swamps of the tropics, or the Everglades of Florida, are often mentioned as better modern analogies. But in all cases, it is something in the nature of a swamp or a marsh or a bog which is used as a parallel. Of

FIG. 298. Tertiary coal at Van Houten, New Mexico. The rock directly above the coal is a conglomerate. (Stanton, U. S. G. S.)

course, if formed by gradual accumulation on the spot where we find them, a cover of water would be necessary to keep the materials from oxidixing too rapidly. The stumps and roots said to be present in the underclay are always referred to as evidence of growth *in situ*. These arguments have hitherto seemed conclusive; and we are told that we have here an ancient soil, which, after having accumulated its load of peatlike material, gradually settled down beneath the waters, and had another layer of earth or sand spread out over it to form the soil for a new growth of vegetation. The land then rises — or the sea

retires, which is the same thing — until this layer of clay or sand is just about the proper distance above the surface again. Thus the same course is repeated age after age, up and down, up and down, there being frequently 75 or 100 successive seams of coal piled one above another, each with its "underclay," and each "underclay" having what are alleged to be the roots of the plants in the beds above.

Difficulties. That the "pulsating crust" could thus rise and fall *ad libitum*, was regarded as being eminently reasonable during the first half of the nineteenth century, for then everyone thought our earth to be fluid inside. However, since the demonstration of the earth's remarkable rigidity, this traditional explanation of the rise and fall of the crust has taken on a much more doubtful cast; but even some who, like Dana, were compelled to accept the earth's essential rigidity, still clung to the old idea of the land's rising and falling, or as they expressed it, "oscillating" at the sea level, in some way not exactly explained.

But when we consider that over wide areas, all these successive coal beds are approximately *parallel to one another* through the whole series of from 50 to 100 successive beds, and that thus all these countless elevations and subsidences must never have disturbed the exact horizontal position of these beds throughout hundreds or even thousands of square miles, but must always have carried them up and down with the same care with which a waiter carries a full plate of soup, another idea suggests itself: How much better it would be if we only supposed the land to be stationary and the sea to be rising and falling, transgressing over the lands and retreating from off them! Of late years, this explanation has been steadily advanced by many eminent scientists; and it would have gained decidedly more acceptance if its defenders could only have shown how these transgressions of the ocean could take place in a few localities without affecting *all the coasts of all the continents* — which is far more than is required.

An objection which lies against either theory is that all these areas affected *must repeatedly have gone through all the experiences of a seabeach;* for "with each foot of submergence, the seabeach would be set a little farther inland, so that the whole would successively pass through the conditions of a seashore." (Dana.) Of this condition there is no evidence whatever throughout these deposits; yet it is difficult to understand how the marks of such a seashore experience could be obliterated, even if such an experience did not destroy entirely the accumulated peatlike deposits.

Here is Professor Dana's naïve statement of the exactness required in adjusting the superior and the inferior limits of the land or of the water, as the case may be:

"For the making of extensive Coal Measures a nice balancing of the land surface between submergence and emergence was a requisite. With a very little too much emergence, even if only a few hundred feet, there would have been no marshes in North America; for the land would have been drained. And with a little too much submergence, limestones or barren sediments of sand or gravel would have covered the region. North America was admirably arranged and poised for the grand result."—*"Manual," pp. 710, 711.*

It is needless to comment on such a statement.

The next thing that claims our attention is a problem connected with the wonderful similarity in the kinds of plants throughout the set of beds in any given locality. At the South Joggins, Nova Scotia, there are 76 successive seams of coal; in the British coal field, England, there are 87 coal beds; in South Wales, over a hundred, 70 of which are worked; in the Liége basin of the Continent, 85; and in Westphalia, 117 successive seams of coal.

No wonder Huxley estimated the length of the Carboniferous period (on the basis of uniformity) at about six million years. Some have made it many times this. But how is it that through all this vast lapse of time, a series of ages so prolonged that our historic period is but the tick of a clock compared with it — how is it that during all this time, the particular plants growing in these localities remained constantly the same, not only unchanged in general aspect, but practically *unchanged even in genera and species?* Whenever in our modern world a region of spruce or pine forests is completely burned over and destroyed, the next growth is almost certain to be some entirely different kind of vegetation, such as maple or birch. In Denmark, three or four such successive forests have occupied given localities within quite modern times, while in New Brunswick and Nova Scotia, as Dawson has shown, a complete change of this character has occurred over and over again within a single generation. But strange to say, during all these uncounted millions of years(?) of the "Coal period," while the country was being "desolated again and again, either universally or partially, by the returning waters, and over the large submerged areas kept desolate for many centuries or series of centuries again and again" (Dana, "Manual," p. 666), the vegetation continued ever the same, the very same plants being found in the upper beds as in the lower, and practically identical the whole world

around, wherever the Carboniferous rocks have been discovered, whether in North American, Europe, Asia, South Africa, or South America. Surely this is a very strange inconsistency which this theory compels us to believe in.

The Underclay. We must next consider the character and conditions of a modern peat deposit. Here we have a bed perhaps 30 or 40 feet thick, made largely of moss which can grow in water alone without earth, or grow on the decaying bodies of its ancestors. Trees of any size do not act thus; for though arbor vitæ, speckled alder, etc., may thrive in wet, swamplike conditions, yet they require to get their roots into real soil even though submerged. So they could not possibly thrive on deposits of purely organic materials of the thickness here spoken of, or where their roots could not reach the soil below. And so far as we are aware, this is the case with all trees, and the huge coal plants ought not to have been any exception to this rule. But suppose we admit that those ancient ferns and club mosses, even though trees in character and size, could have lived and thrived in peatlike accumulations of any thickness, and that they did not need to have their roots in real soil. But even the thickest seams of coal, say 30, 40, or 50 feet in thickness, have their "stigmaria" or rootlets in the lower part, just as do the thin beds. We must also remember that for each foot of coal, we require several feet in thickness of organic material; the usual estimate seems to be that about 10 or 12 feet of peatlike deposits would be required to produce one foot of good coal. Thus we would have 300 or 400 or 500 feet of peat as quite a common thickness for the larger sort of these ancient deposits.

Now we shall hardly be prepared to claim that the roots of even the giant plants of the "Coal period" could thus reach down through these 300 or 500 feet of deposits to the soil below. The alternative is that the roots of the first plants must have remained intact and unaffected by decay all the centuries that these 300 or 500 feet of deposits were being built up. Either way, the case seems absurd.

But it frequently happens that a fossil tree is found extending up through two or more of these successive beds of coal, together with the intervening beds of shale or sandstone. Evidently in these cases, the coal was not formed in the manner described by the current theory.

Another difficulty is that if the first plants lived and thrived in the soil before there were any peatlike accumulations, the same plants could hardly be expected to grow well in the top layers when there was nothing but peat,— no soil whatever

within reach. Frequently, also, these bands of shale or sand, the so-called "underclays," separating two successive seams of coal, are only one, two, or three inches in thickness, an utterly insufficient amount for a soil in which trees are supposed to grow.

Thus it seems that in every way in which we can get at this theory from the *a priori* point of view, the evidence breaks down completely.

The Sedimentation Theory. However, it should be noted here that not all geologists teach this peat-swamp theory, with its incredibly delicate oscillations of level. The French geologists, with others on the Continent, hold strongly to another explanation, called the theory of *sedimentation,* which claims that the plant material of ordinary coal does not represent growth *in situ,* but that it drifted to its present position in much the same way as ordinary sedimentary rocks.

Without going into a detailed consideration of this theory or of the arguments by which it is supported, it is quite evident that, to those who hold it, the alleged presence of rootlets in the "underclay" must be of very little weight. And this French theory, if we may so term it, evidently explains the surprisingly regular "alternation of conglomerate sandstone, shale, and coal seams observed in most coal basins" (Zittel) far better than the other theory. Still it fails to explain the almost universal presence of exquisitely preserved leaves and other parts of plants in the accompanying shales; and it is perfectly helpless in the presence of crinoids and corals and radiolarians alternating regularly with the coal seams, or what is still worse, in the presence of limestones and coals, which are sometimes even mingled together.

That the coal beds themselves are usually as thoroughly *stratified or bedded* in their structure as are the conglomerates and the sandstones, is proved by their frequent lamination, and even their alternations in shades of color. (Dana, "Manual," p. 709.) As for the "underclay" itself, it admits of only one rational explanation in the case of either theory, and so proves nothing for either side. Even if the coal plants were deposited by a wholly abnormal kind of sedimentation, with great quantities of the plants perfectly fresh and green, as may have been the case, the acids generated in the decomposing mass, carried along by the water percolating from above, would dissolve or carry to the bottom of the bed practically all the earthy matter which would necessarily at first be scattered through the mass of vegetable matter. This is why coal is so purely

carboniferous, and also why we generally find perfect plant specimens only in the upper part of the seam, or in the shales above the seam.

Professor E. A. N. Arber, of Cambridge University, has given us some very enlightening remarks about the "underclays." He says that "nothing could be more unlike a soil, in the usual sense of the term, than an underclay." ("Natural History of Coal," p. 95.) He further points out:

"Not only are fire clays commonly found without any coal seams above them, but they may occur as the roof above the seam, or in the seam itself. . . . Sometimes coals occur without any underclay, and rest directly on sandstones, limestones, conglomerates, or even on igneous rocks."— *P. 98.*

"Another difficulty in connection with underclays is that their thickness commonly bears no relation to the extent of the seam above. Often thick coals overlie thin underclays, and *vice versa.*"

Regarding the many instances of upright stems, this author argues that —

"These stems in some instances are certainly not *in situ.* Examples have been found which are upside down, and in some districts the prone stems far exceed those still upright. No doubt the majority, if not all of these trunks, have been drifted."— *P. 114.*

The Opinion of Suess. It is a decided relief to take up a work like that of Eduard Suess, and see how this most accomplished scientist makes quite impossible and absurd the old theory of the oscillation of the land. One of his arguments against the common theory of the formation of the coal, is that there are many instances where coal beds do not rest upon anything like an "underclay," but directly on shale or limestone. Another is that in very many cases, "thick beds of coal split up into a number of smaller seams, which become separated further and further from one another by the thickening out of intercalated wedges of sterile rock" ("Face of the Earth," Vol. 2, pp. 244-246), a thing that would be clearly impossible on the basis of the current theory. Thus in Staffordshire, England, the main coal bed, 25 feet thick, splits toward the north into 8 seams, in such a manner that the sum of the seams and the intervening beds amounts to 390 feet.

But this work of Professor Suess also has its disappointments; for while the author sees the errors of the old theory, he has little better to offer in the way of explanation, and he gives the following summary of the situation, which will bear repetition here:

"Although many thousands of men work day and night in our Coal Measures, and although many acute observers are led by their profession to make the study of these deposits the

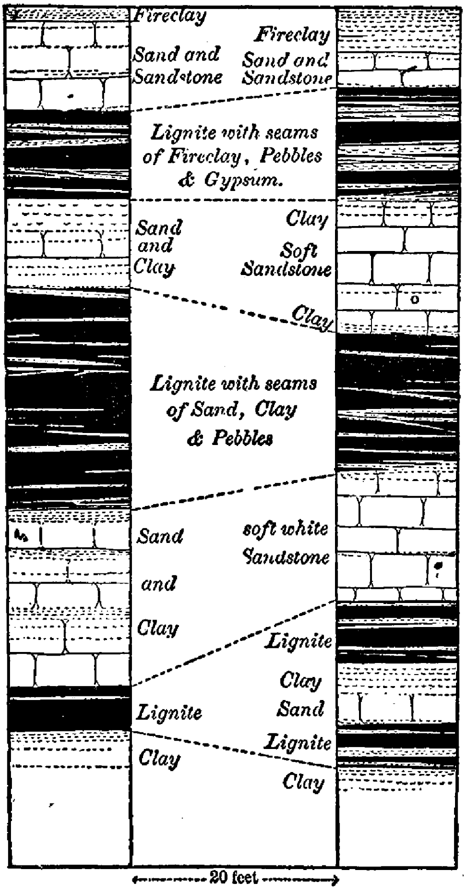

FIG. 299. Parallel vertical or columnar sections as shown on the face of Pulpit Rock, near Colorado Springs, through identical strata, and only 20 feet apart. These sections show how rapidly the strata change when followed only a short distance. Notice how the thin partings between the coal seams in one section become wide strata in the other. (After Grabau and Crosby.)

business of their life, yet the mode of formation of the coal beds is still far from being satisfactorily explained."— *P. 244.*

The Probable Method of the Formation of the Coal Beds. If we care to go into the question of probabilities, and can picture to ourselves a wide stretch of country clothed for long periods with a most luxuriant vegetation, and if we may suppose that the remarkable atmospheric conditions of the ancient world may have absolutely precluded any parching drought, thus rendering it quite improbable that the accumulated deposits of centuries should ever be burned up by forest fires, we shall have the probable *source of the materials.* If now, in the great world catastrophe which seems to be indicated, these accumulations of many centuries were all washed away, dead and green together, and swept pell-mell into lakes or valleys, somewhat like the great natural "raft" on the Red River, only on a far more enormous scale, the stumps of the trees would still carry many of their roots with them, and would frequently float in the natural or upright position. In this case, too, we would ultimately have the formation of an "underclay" at the bottom of the bed from the action of the acids generated in the oxidizing mass; and this "underclay" would naturally contain many roots or something resembling them. Thus these two conditions are accounted for.

Coarse conglomerates or gritty sandstones very generally underlie the coal beds or are sometimes intercalated with them, as the Millstone Grit of England and the Pottsville conglomerate of Pennsylvania. These conglomerates and grits point to large volumes of water in sudden and violent action.

Marine Remains Mixed Up with the Coal. But let us consider another proof of how these coal beds were formed; namely, the remarkable way in which various kinds of marine life are mixed up with the coal. We have already spoken of the deep-sea crinoids and the clear-water ocean corals, both of which often alternate with the coal beds; and we have drawn the conclusion that these conditions indicate an abnormal tidal action. We need not repeat the evidence here.

The proofs of vast numbers of fishes having been entombed in the deposits forming the cannel coals, are of the same import. Indeed, as Dana says:

"The great number of fossil fishes in some very carbonaceous or bituminous shales, has led to the suggestion that fish oil may have been the sole source of the oil or gas yielded by the shales. It is not improbable that it was a prominent source, since the same process which will convert vegetable tissues into coal or mineral oil, will produce a like result from animal oils."—*"Manual," pp. 655, 656.*

We have already spoken of the small chance which vertebrate fishes have of being fossilized under our modern conditions. Dana himself says that they "require speedy burial after death, to escape destruction." And it should be remembered that the stagnant, poisonous waters of our modern swamps or bogs do not thus teem with fishes.

Quite evidently these enormous deposits, thus packed full of fish remains, must have been formed in some wholly abnormal manner. Nothing at all resembling such things has ever been formed within the historic period. But we must remember that these fossil conditions are absolutely world-wide in extent, and are scattered through almost all the various formations.

Pyrites. Another interesting side light upon the question of how the coal beds were formed, is supplied by the frequent presence of various compounds of sulphur. Thin layers of *pyrite* are very common, the percentage in the anthracites being a little over one per cent, while in the coals of Ohio and Indiana and Illinois the average is over two per cent. The coals from Nova Scotia and the anthracites of Pennsylvania seem to have very little sulphur, and they contain very scanty traces of marine fossils. But all the other coals are interbedded with strata which contain relics of marine faunas; and it is now known that *the presence of sulphur is due to the action of sulphur-making bacteria which exist only in connection with sea water.*

Hydrogen sulphide is found in great abundance in modern peat beds to which sea water has access, and is seldom found in peat which forms under fresh water. Thus the presence of sulphur in these coal beds is "an indication that the sea water had access to these beds while the vegetable matter was still recent." ("Acadian Geology," p. 164.) Even common salt, in the form of brine, is sometimes present in the coal.

Two other features characterize the coal beds as a whole,—the lignites and the brown coals, as well as the true coals of the Coal Measures,—and these features should decide the question of how the coal beds were produced. These two lines of facts are (1) the well-preserved character of the plant remains; and (2) the kinds of plants composing them.

Condition of the Plant Remains. With regard to the wonderful perfection with which the plants are found preserved in the accompanying beds, Sir Archibald Geikie says:

"Not much is usually to be made out from the coal itself, for the vegetation has been so squeezed and altered that the leaves and branches of the plants can no longer be recognized. . . . But though the larger plants have not usually been preserved well in the coal itself, they may sometimes be found in great profusion and beauty in the beds of rock above or below the coal. . . . Now and then, the plants may be seen lying across each other, in wonderful profusion, upon the bottom of the bed of rock that overlies the coal seam and forms the roof of the mine. Though all squeezed flat like dried leaves in a book, they still retain their original graceful forms."—*"Primer," pp. 68, 69; 1893.*

Most geologists who have written upon this subject have bewailed the poverty of our language to convey any adequate idea of the marvelous perfection of the forms laid out to view by the thousands through the opening up of such beds of shale or fine sandstone.

Evidently such things could not have lain for centuries rotting in a swamp or peat bog. But this splendid preservation of the plant remains is a universal characteristic of all the coal-bearing rocks, not alone those of the Carboniferous system, but also those of the Jurassic, Cretaceous, or Tertiary, or even the lignites of the Pleistocene. They are all much alike in these respects; they all contain wood or leaves, flowers and fruits, in a marvelous state of preservation; "with all the perfection they have in an herbarium." (Dana.) On this point, certainly, we must conclude that these ancient accumulations of plant remains were not formed as our modern peat bogs or swamps are now being made.

Kinds of Plants. But the kinds of plants contributing to the formation of the coal beds, have also a very important bearing

on the problem of how these beds were formed. The plants of the Coal Measures proper are always spoken of as ferns, cycads, equiseta, lycopods, etc.; and our ignorance of how they actually grew has made it seem reasonable to suppose that they may have grown on wide, damp plains, with plenty of moisture above and below. But it must be remembered that "the ablest botanists," as Dr. Page observes, are "yet unable to assign them a place among existing genera." ("Textbook," p. 134.)

However, these Carboniferous coals constitute only a portion of the total coals of the world, all the subsequent systems con-

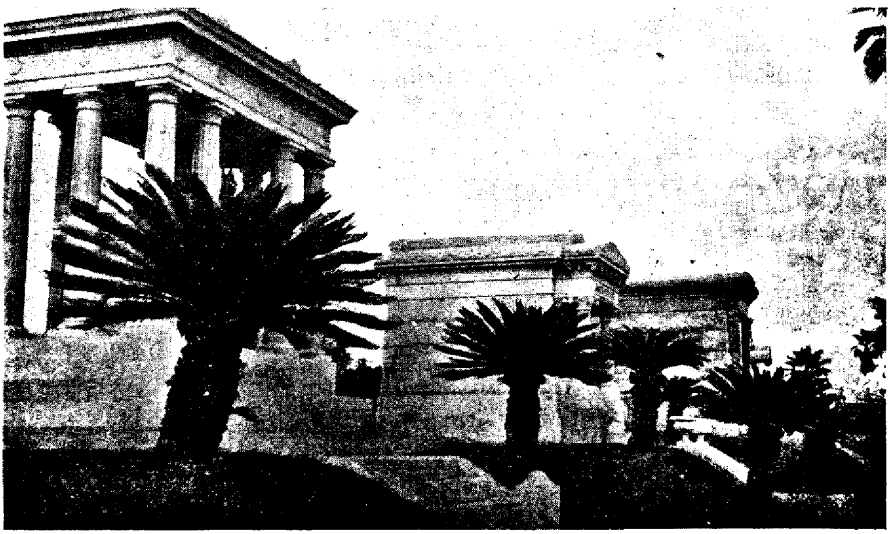

FIG. 300. Cycads growing in a cemetery, New Orleans, Louisiana. (Lee, U. S. G. S.)

taining vast coal deposits. And if we ask ourselves what kinds of plants produced these coals of the Cretaceous, Tertiary, and other formations, we have to reply that they are chiefly plants and trees which do not grow in swamps or bogs, and can not, by any stretch of the imagination, be supposed to have contributed to the formation of any peatlike accumulations in the long ago. For example, we have in the Upper Createaceous such kinds as sassafras, laurel, tulip tree, magnolia, *Aralia,* cinnamon, sequoia (like the "big trees" of California), poplar, willow, maple, birch, chestnut, alder, beech, elm, with the leaves of some palms, and hundreds of others. In the Tertiary of England and the Continent, we have such trees and shrubs as fig, cinnamon, various palms, varieties of *Proteaceæ* (like those of India and Australia), cypress, sequoia, magnolia, oak, rose,

plum, almond, myrtle, acacia, with many other genera now found only in America. The Miocene strata of Greenland have yielded great numbers of the same genera. It would thus seem that in whatever way we examine this problem of how these ancient plant deposits were formed, we are confronted with evidences of some very abnormal action of the elements, essentially different from any conditions now prevailing.

Climate. David White has given us a very careful study of the climatic conditions indicated by the coal deposits. He first tells us that "well-developed coal has been found in the strata of every period since the Silurian" ("Origin of Coal," p. 1); and then proceeds to say that —

"During the times of deposition of most of the principal coal groups the climate has been characterized by —

"(1) General mildness of temperature, approaching in most cases tropical or subtropical;

"(2) Conspicuous equability or approximation to uniformity of climatic conditions; . . .

"(3) A generally high humidity; . . .

"(4) An amazingly wide geographical distribution of these genial and equable climates, which occurred seemingly in almost uniform development simultaneously in the high and in the low latitudes of both the Northern and the Southern Hemisphere." —*P. 68.*

Next he gives his reasons for these conclusions, though we can give here only a brief outline of the facts which he presents. But these conclusions are based on the following criteria:

"1. The relative abundance or luxuriance and large size of terrestrial vegetation — that is, rankness of growth — indicating favorable conditions of temperature, humidity, etc.

"2. Character, condition, and amount of land-plant material . . . indicates humidity.

"3. Great radial distribution, seemingly over the greater part of the earth, and especially over wide ranges of latitude, of identical species and genera in characteristic association, indicating the extension of approximately uniform climatic conditions in these regions.

"4. Presence of types known to be adapted to or confined to the warm temperatures or moist climatic conditions of the present day.

"5. Structures of the plants themselves. Features showing rapidity of growth; that is, abundant rainfall, mild or warm temperatures, etc.— conditions favorable to rapid growth:

"(*a*) Very large size of the cells, many with thin walls, and large intercellular spaces, indicating rapid growth and abundant moisture, noticeable in the woods found in and with most coal.

"(*b*) Large size of fronds and leaves.

"(*c*) Frequency of laciniate or much-dissected, drooping fronds and pendant branches or twigs.

"(*d*) Smoothness of bark, which is often thick, pointing toward warm humid swamps.

"(*e*) Absence of growth rings in the woods of the older coal formations, showing climatic conditions favorable to practically uninterrupted growth, and the absence of long dry seasons or winter frost."

F. H. Knowlton, in commenting on these facts, agrees fully with White in the above conclusions, and declares that there was *"a non-zonal arrangement"* of climate prior to the Pleistocene. (Bulletin of Geological Society of America, Vol. 30, p. 541.) He further declares that the temperature of the oceans was everywhere the same and without "widespread effect on the distribution of life." (P. 548.) And he summarizes this matter of climate in the following words:

"Relative uniformity, mildness, and comparative equability of climate, accompanied by high humidity, have prevailed over the greater part of the earth, extending to, or into, polar circles, during the greater part of geologic time, since, at least, the Middle Paleozoic. This is *the regular, the ordinary, the normal condition."— P. 501.*

Knowlton further confirms the conclusions of White, and says the argument of the latter *"applies with equal force to all horizons,"* and even goes so far as to affirm that even the *red beds,* so often pointed out as proofs of arid or desert conditions, "may have been formed under conditions of warm, moist climates." (P. 506.)

CHAPTER XXXI

The Mesozoic Group—The Triassic System

Historical. Some of the rocks of the Mesozoic group were among the earliest stratified rocks with which geologists became acquainted, chiefly because in Central Europe they were long ago worked for their minerals and ores. In these localities, the strata now called Mesozoic rest directly upon the old crystalline rocks, which were called *primitive* or *Primary*. Hence the rocks above the latter were called *Secondary*, a name which lingered with them for a very long time, the term *Mesozoic* having been adopted only within recent years. In other localities also, these Mesozoic formations rest directly upon the Pre-Cambrian or primitive rocks, as in the Plains States of Western America, and in Sonora, Mexico; so that in a certain sense, it might be said that in these strata we are starting again from the bottom, as we did at the beginning of the Paleozoic.

In England, where these rocks were first studied scientifically, these Mesozoic (Secondary) beds were separated into three distinct sets or systems, the *New Red Sandstone*, the *Oölites*, and the *Chalk*. These have since been called the *Triassic*, the *Jurassic*, and the *Cretaceous*, respectively. And this usage has been extended wherever geological exploration has extended.

The New Red Sandstone of England proved to be the equivalent of rocks with a threefold serial division in Germany, which were designated as the *Bunter Sandstein*, the *Muschelkalk*, and the *Keuper*, this characteristic threefold division giving rise to the name *Trias*, and later to the more modern *Triassic*. Still later a sixfold division was adopted on the Continent of Europe; but here it will be sufficient for us to speak of merely a *Lower*, a *Middle*, and an *Upper Triassic*. In America, for a long time, there was not a clear distinction made between the Triassic and the Jurassic, many deposits being designated by the combined name, the *Jura-Trias*. But more recently a distinction has been made between these systems.

Subdivisions. Thus the Mesozoic group is made up of the three systems:

3. **Cretaceous**; named from the chalk (Latin, *creta*, chalk) beds which are common in the regions where this system was first examined.

2. **Jurassic;** named from the Jura Mountains, between France and Switzerland.

1. **Triassic;** so named from the threefold division of these rocks in Germany, where first studied. The name thus early

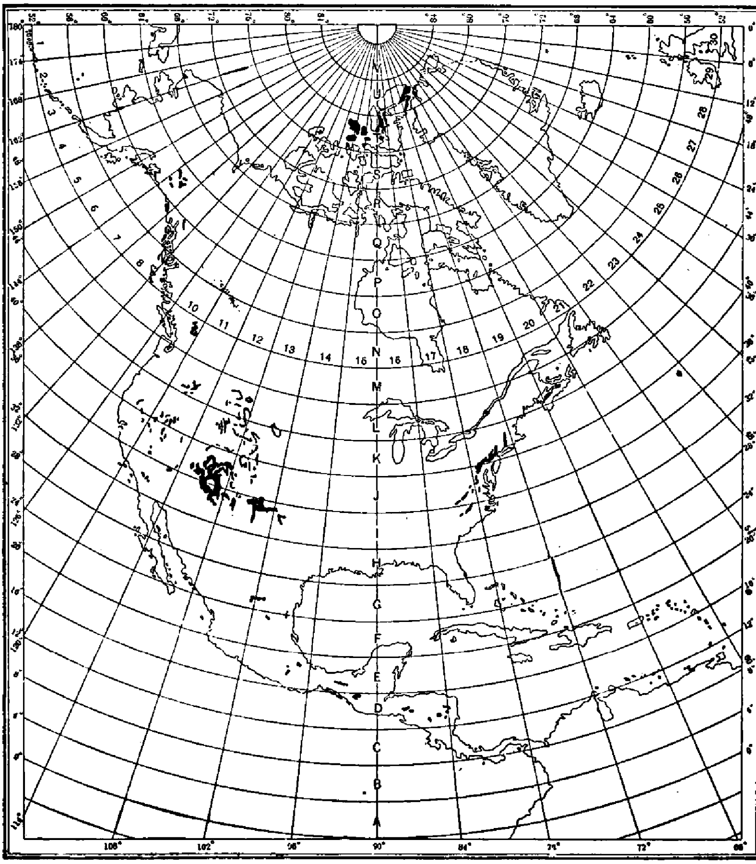

FIG. 301. Map showing the distribution of Triassic rocks in North America, including some undivided Triassic and Jurassic rocks.

adopted has persisted, in spite of the fact that in other countries, this threefold character does not often occur.

General Characters of the Mesozoic. The earlier works on geology very strongly emphasized the fact that a complete change in the types of life is noticed in passing from the Paleozoic to the Mesozoic group, a change so complete, it was said, that none of the species of the former group are found in the latter, and few of the genera or tribes. This came about from the artificial way in which these groups were constituted,

the distinction being wholly a biological one, based on the principles of systematic classification. On the other hand, in actual field work, it has frequently been found that there is no such sharp line of distinction between the two groups. Not only do Mesozoic strata frequently occur *conformably* on strata of the Paleozoic (and not always the Permian, or Upper Paleozoic), but strata are often found extending over wide areas, as over the larger part of China and Eastern Asia, where no stratigraphical break can be discovered between the two groups. Of course, in a general way, the types of plants and animals in the two groups are very different, for the very simple reason that one group has been built up from certain kinds of fossils, and the other from wholly different kinds of fossils. As reptilian types are the most abundant and the most characteristic fossils of the Mesozoic strata, this group used to be spoken of as indicating an "Age of Reptiles."

The Triassic — Kind of Rocks. In America, the Triassic rocks are chiefly conglomerates and granitic sandstones, with some impure limestones here and there. The sandstones are usually red or brownish red. Fresh undecomposed grains of feldspar are often found along with the quartz, making what is called *arkose;* and much of the sandstone thus composed has the exact constituents to produce granite again under the metamorphic action of heat and pressure. The condition of these grains of feldspar and quartz is often such as to indicate that they had not been much exposed to the action of the air and the waters.

Besides the coarse conglomerates, which in many instances contain stones three or four feet across, the beds frequently have a marked cross-bedded structure, with other evidences of strong currents.

Distribution. Rocks classed as Upper Triassic are found in isolated localities along the Atlantic border from Cape Breton Island to South Carolina. They are generally red in color, and consist of shales and sandstones, with occasional conglomerates. They show mud cracks, rain imprints, the tracks of reptiles, and are often strongly cross-bedded, showing that they are probably not of marine origin. In New Jersey and the Connecticut Valley, and also to the south, are black shales in which are the remains of ganoid fish "wonderfully well preserved." (Grabau.) In Virginia and North Carolina are workable seams of coal, some of the plants associated with these beds being like the beds classed as *Rhætic* (Upper Triassic) in Europe. The

small crustacean, *Estheria*, quite characteristic of this formation, occurs in great numbers in the black shales associated with these coal beds.

Extensive igneous rocks, largely basaltic, are associated with the Triassic formations near the head of the Bay of Fundy; while the great diabase near Holyoke, in the Connecticut Valley, nearly 3 miles wide and 400 feet thick, is assigned to this system, according to the usual custom of geologists, because associated with Triassic beds. Similar igneous intrusions oc-

FIG. 302. Base of the Palisades of the Hudson, Weehawken, New Jersey. This shows the very irregular contact of the diabase sill with the underlying shales. (U. S. G. S.)

cur farther south, the famous Palisades on the Hudson being also classed as Triassic. Dana very pertinently remarks that these igneous masses "are so associated with the sandstone formation that there must have been some connection between the water-made and the fire-made rocks." In some of these igneous outflows in Nova Scotia and New Jersey, "the lava flows seem to have covered bodies of shallow, standing water, or overspread a flood-plain deposit still saturated with water. In such cases, the base of the lava sheet was rendered porous by the resulting steam, while sand and mud are not infrequently carried up into the lava sheet for some distance by the violent activities of the expanding steam." (Grabau.) (Fig. 302.)

Some of the rarer minerals are often found in the pockets resulting from such igneous action.

But far more extensive areas of Triassic rocks occur in Arizona, New Mexico, Utah, and Colorado, the front ranges of the Rockies being also largely assigned to this system. The famous "Petrified Forest," so-called, of Arizona, is classed as Triassic. Here we have giant trees, most of them being *araucarians,* like the Norfolk Island pines, so extensively used for decoration purposes, and grown outdoors in California, which

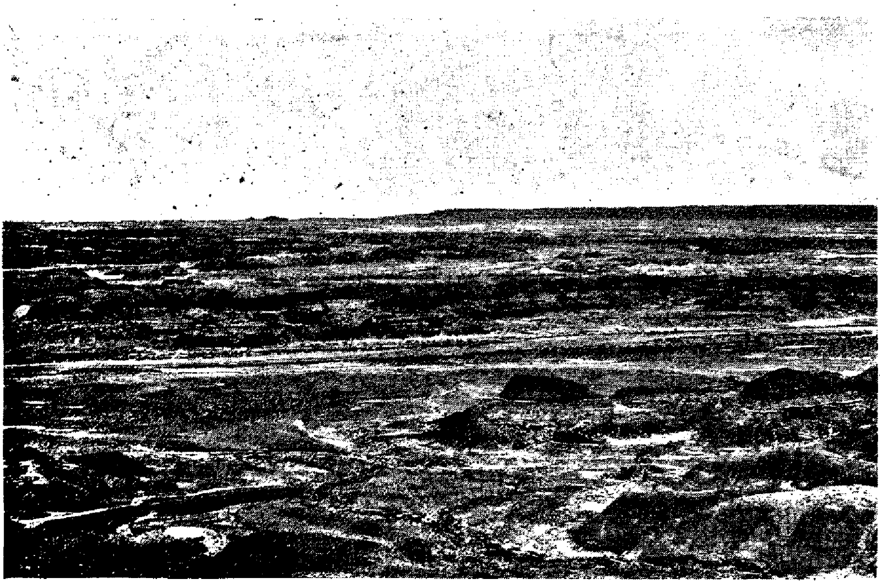

FIG. 303. General view of the "Petrified Forest," Arizona. Lithodendron Creek, Apache and Navajo counties. (Gregory, U. S. G. S.)

are now natives of the Southern Hemisphere. Some of these tree trunks are over 100 feet long and 6 feet in diameter. They are all prostrate, and are broken into sections, the wood having been replaced by silica in the form called *chalcedony,* with many beautiful bands of brilliant colors, brown, yellow, and red, due to the iron oxides present.

On Vancouver and Queen Charlotte Islands, and elsewhere in the southern part of British Columbia, Triassic beds are found. Basalts near Mount St. Elias are assigned to this system, which seems to be of wide extent in Alaska, and on several of the islands in the Arctic Ocean, as well as on each side of Greenland. The plants found in these regions show a warm or temperate climate.

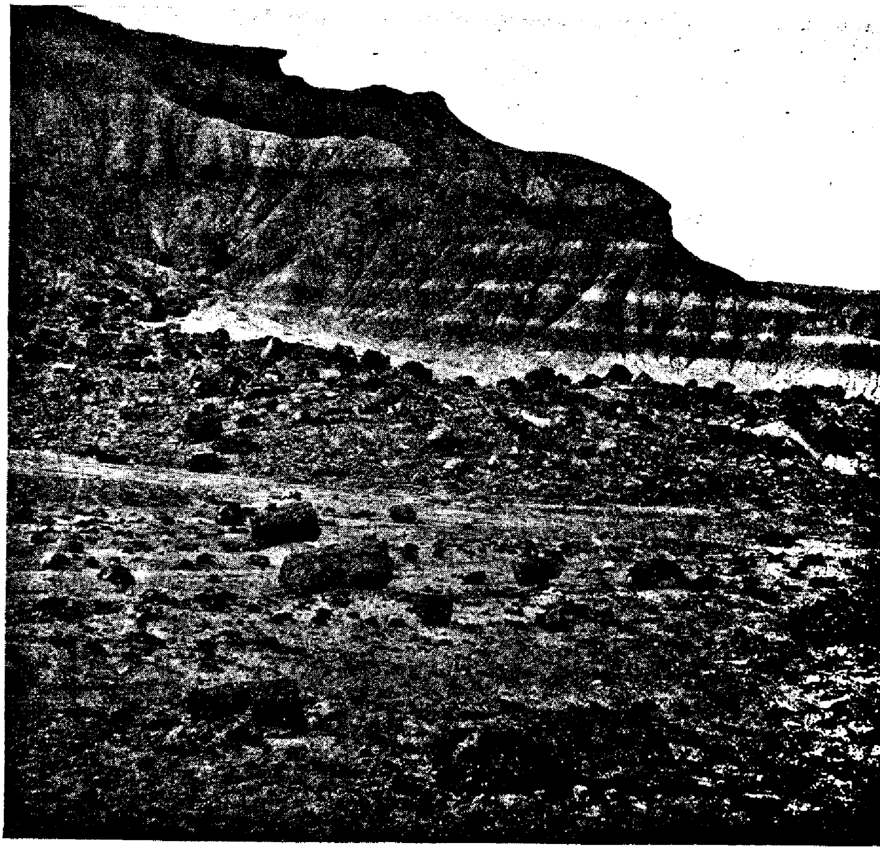

FIG. 304. Log-bearing beds, "Petrified Forest," Arizona. The petrified logs, being much more resistant to weathering, have been left behind after the matrix of the beds has been carried away. (Darton, U. S. G. S.)

Triassic beds are known in Inyo County, and also west of Lake Tahoe, California, and in the West Humboldt range of Nevada. Fossils very similar to the Triassic beds of Spitzbergen, Tibet, the Himalayas, and Southern Siberia, have been found in these California strata.

In Sonora, Mexico, in Central America, and again in the high Andes of Peru, are strata identified as Triassic.

The red color, which first gave these formations the name of New Red Sandstone, is a very common characteristic of the Triassic all over the world. But we have already learned of the vast *laterite* deposits in the tropics and even in subtropical localities, as in the southern Appalachian Mountains, where the old crystalline rocks of almost every kind are decomposed into a red clay which extends to depths of 100 feet or more.

FIG. 305. "The Twin Sisters," "Petrified Forest," Arizona. (Darton, U. S. G. S.)

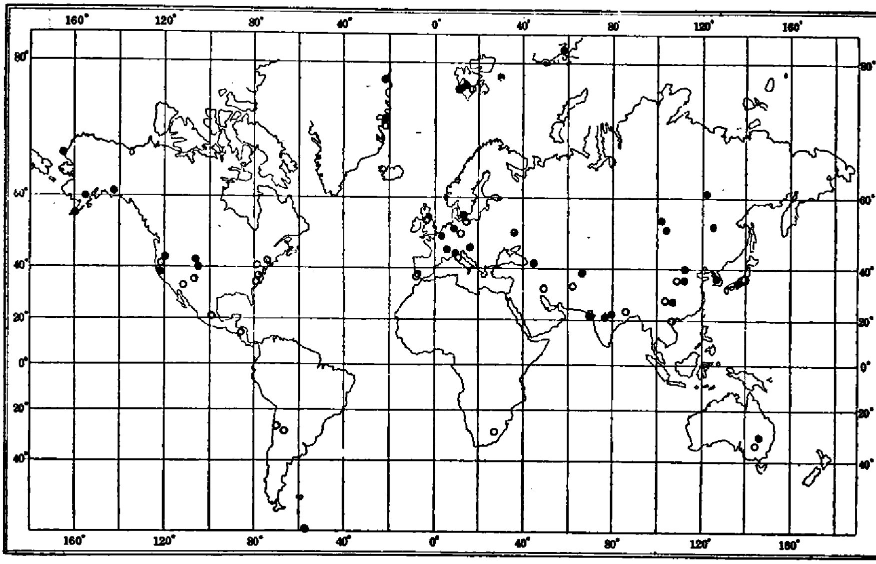

FIG. 306. Map showing approximate distribution of Triassic and Jurassic floras. Rings, Triassic; dots, Jurassic. (After Knowlton, U. S. G. S.)

This laterite is a *porous clay, colored red with iron oxide;* and it is formed by the minute grains of quartz becoming covered over with a reddish film. The red laterites of the warm climates "may be derived from very many different kinds of parent rock, igneous rocks, crystalline schists, limestones, and dolomites." (Scott.) This helps us to understand how the Triassic rocks are so often alike in appearance, this appearance being simply due to similar chemical conditions in the rocks, either before or after deposition, for a change from yellow iron oxide to red can even take place by chemical dehydration underground, after the sediments have been deposited. (Grabau.) And thus it is not at all necessary for us to imagine that these Triassic rocks were formed in an arid climate. The luxuriant vegetation represented by the coal beds and by such formations as the "Petrified Forest" of Arizona, are good evidence that the climate in which these floras grew was anything but arid. No true desert plants have ever been found in any of the fossiliferous rocks. (Macdougal.)

Foreign. In Germany, as we have seen, the Triassic beds are well shown; and they also cover much of the central plains of England, Northeastern Ireland, and small localities on the east coast of Scotland. In France, they are seen in the eastern and southern parts of the country, and also around the border of the central plateau region. They occur in Eastern and

Southern Spain, and are well developed in Italy directly to the south of the Alps, and also in the northern Apennines, and in Southern Austria. The famous white Carrara marble of the Apuan Alps, Italy, is a metamorphic Triassic limestone.

In many isolated parts of Asia, Triassic rocks have been observed, these disconnected spots running across the continent to the eastern border. The *Salt Range* of Northwestern India near the Himalayas has already been mentioned as being in part Permian; but it is Triassic in its upper portion, as are also the *Gondwana series* with their Glossopteris flora. In Japan also, and on the eastern coast of Siberia, as also in the arctic islands of Spitzbergen and Bear Island, Triassic beds with characteristic fossils of both plants and animals have been found.

The *Karoo beds* of South Africa, which are partly Permian in their basal conglomerates, are Triassic in their upper formations. Coal beds of Triassic facies are found in Queensland and New South Wales, Australia, and the Triassic are also found extensively in many of the islands of the Indian and the Pacific Ocean, as Sumatra, Borneo, and many others.

Life

Plants. Triassic coal beds, composed of the characteristic plants of this system, are found in such widely scattered regions as Virginia, Alaska, Germany, Sweden, South Africa, and Australia. They consist chiefly of ferns, horsetails, cycads, and many kinds of conifers.

A magnificent fern, *Macrotæniopteris,* with broad banana-like leaves, is found in great numbers in Virginia. In other

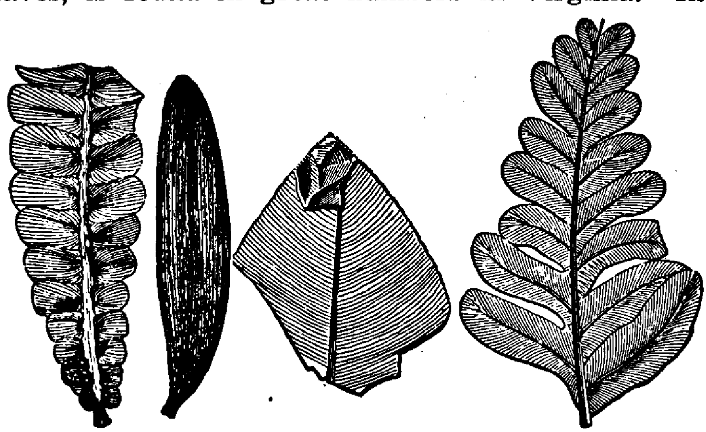

FIG. 307. Upper Triassic (Rhætic) plants. *a, Otozamites macombii; b, Podozamites crassifolia; c, Tæniopteris elegans; d, Alethopteris whitneyi.* *a, b,* cycads; *c, d,* ferns. (After Newberry.)

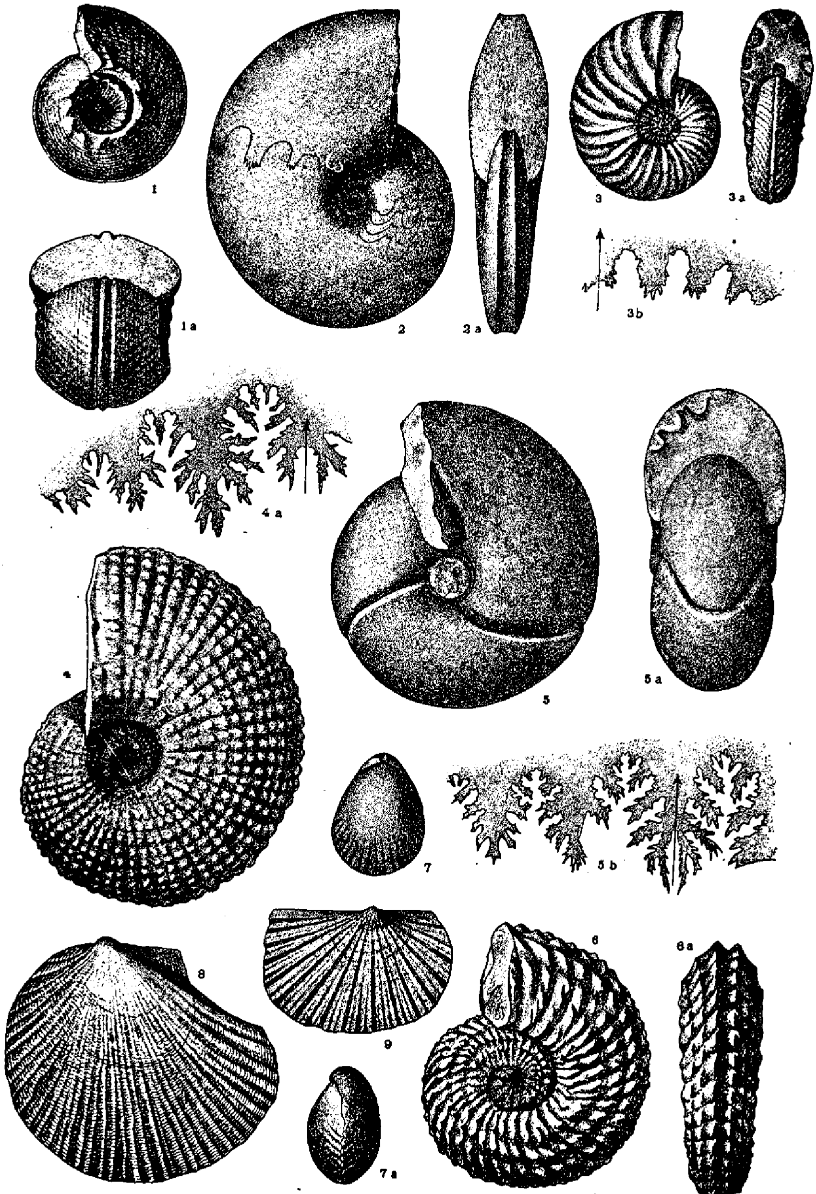

FIG. 308. TRIASSIC INVERTEBRATE FOSSILS

1, 1*a*, *Tropites subbullatus*, Hauer, side and end views, × ½, U. Tr. 2, 2*a*, *Meekoceras gracilitatis*, White, side and front views, L. Tr. 3, 3*a*, *Gymnotoceras blakei*, Gabb, × ½, side and front views, M. Tr. 3*b*, *The same*, a suture line, × 1. 4, *Sagenites herbichi*, Mojs., × ½, U. Tr. 4*a*, *The same*, a suture line, × 1. 5, 5*a*, *Joannites nevadanus*, Hyatt and Smith, × ½, side and front views, M. Tr. 5*b*, *The same*, a suture line, × 1. 6, 6*a*, *Analcites meeki*, Mojs., × ½, side and back views, M. Tr. 7, 7*a*, *Terebratula semisimplex*, White, × 1, dorsal and side views, L. Tr. 8, *Pseudomonotis subcircularis*, Gabb, × ½, M. Tr. 9, *Daonella lommeli*, Wissmann, × ½, U. Tr. (After W. B. Scott, "Introduction to Geology," permission of Macmillan Co.)

localities, true horsetails belonging to the living genus *Equisetum* are more abundant. They were immense plants, with stems 4 inches in thickness. Their stems and rhizomes are very abundant, and doubtless they helped to form the enormous vegetable accumulations which were buried and afterwards turned into coal. The cycads belong, in many instances, to the modern or living genera, and they are in such great numbers that these and other Mesozoic formations used to be spoken of as belonging to an "Age of Cycads." *Gingkoes* are common; but even of greater importance are the splendid *araucarian pines,* like the Norfolk Island pine now so common in South America, Australia, and Polynesia. The cypresslike *Voltzia,* which also is common in these coal formations, is of the dry-land variety and not of the swamp-loving kind. The gingkoes and the araucarians also have their habitats in dry, well-drained regions, and not in anything like swamps or bogs. Hence it would seem that the old swamp-bog theory for the origin of the coal beds would not apply to these Triassic coal beds.

Invertebrates. *Corals* belonging to the living group *Hexacoralla* are the common reef builders represented in the limestones of the Triassic. Coralline seaweeds, or calcareous algæ, contributed very materially to the formation of these ancient limestone deposits. Sea urchins are not common, while the crinoids belong chiefly to the genus *Encrinus.*

The little crustacean *Estheria* is very common in some of the Triassic beds; but otherwise crustaceans are not very numerous. Insects occur, beetles being found in addition to the two orders of insects already mentioned from the preceding systems.

Brachiopods are far less plentiful than in the preceding formations. A few specimens of *Productus, Athyris,* and *Cyrtina* are occasionally found; but the more common kinds are those with short, curved hinges, such as *Terebratula* and *Rhynchonella,* which are still existing genera.

Of the *Mollusca,* the true bivalves, or Pelecypoda, are much more varied and more numerous than in the other formations which we have been considering under the Paleozoic group, *Pectens, Carditas,* and other modern-looking genera being here represented. Gastropoda are sparingly represented; but the Cephalopoda, especially the *ammonoids,* are profuse in their abundance and in great variety. The ammonoid cephalopods are minutely subdivided in order to serve as "index fossils," the distinctions being based largely on the suture lines showing on the sides of the shell. The related dibranchiate cephalopods

known as *belemnites* are also found in these rocks, though they are more common in some of the succeeding Mesozoic formations.

Barrande asserts, however, that the Triassic Nautilidæ show less affinity to the modern species than do those of the Paleozoic; in other words, the existing species of this group are more closely like the so-called "oldest" forms than the forms of these

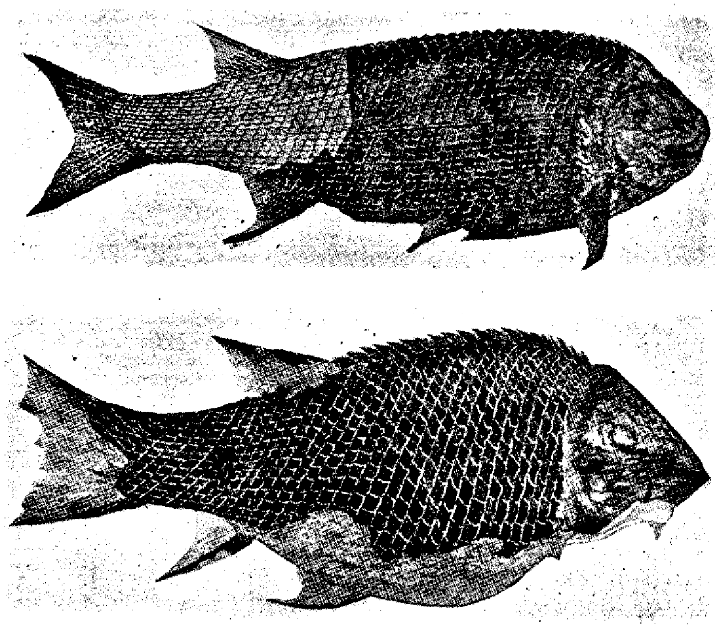

FIG. 309. *Catopterus redfieldi,* from the black shale in the Triassic sandstone of the Connecticut Valley and New Jersey. (After Newberry.) *Ischypterus micropterus,* from the black shale in the Triassic sandstone of the Connecticut Valley. (After Newberry.)

Mesozoic or "Middle Age" formations. (Heilprin, "Geographical and Geological Distribution," p. 188.)

Vertebrates. Among the *Vertebrata,* fishes are not very common, though shark teeth are found, and the dipnoan *Ceratodus,* or lungfish, is quite characteristic of the Triassic. Ganoids like the existing gar pikes are fairly common, with occasional curious-looking types, like the *Diplurus,* which belongs to the crossopterygians.

Amphibians, especially those belonging to the *Stegocephalia,* are exceedingly common and greatly diversified, some of them being very large. They have been found in North America, in South Africa, and in Europe, "the Bunter sandstone of Germany being a treasure house of such remains." (Scott.) Sev-

eral of the formations containing their fossils are called *bone-beds.* But it is a very expressive commentary on the artificial method of arranging the fossils in alleged chronological order, that the whole group of *Amphibia* seem to *skip from the Triassic to the Oligocene of the Tertiary* (Gadow, "Cambridge Natural History," Vol. 8, p. 83), though a stray salamander or two occur in the Cretaceous.

The *reptiles* are very common and show a great variety of forms, though their remains are more common and better preserved in the European Triassic than in the American. But essentially the same genera occur in the two regions. All the great orders of the Reptilia are represented in the Triassic, though the *ichthyosaurs* and the *plesiosaurs* which are here found are not the gigantic kinds found in the subsequent systems of the Mesozoic. The *Dinosaurs* also are not so common or so monstrous in size as those found in the Jurassic and the Cretaceous, though some footprints of them have been found which are from 14 to 18 inches long. A subsequent chapter will deal more at length with the fossil Reptilia.

However, the *chelonians* (tortoises and turtles) are very common and are found in many diversified forms. Some had cutting jaws, like modern turtles, but others had a pair of large tusks in the upper jaw. One genus of this group, *Dicynodon,* has been found in Scotland, Russia, India, and South Africa. Others of these fossil Chelonia, as they are usually called, the *Therodontia,* were much like mammals in their dentition, and have left a great profusion of remains in the Karoo beds of South Africa, and also in India.

CHAPTER XXXII

The Jurassic System

History. The formations included in this system are some of the most widespread and important in Europe, though they are of inferior importance in America, except in the Rocky Mountain region. Early in the nineteenth century, William Smith worked out the leading subdivisions of this system from the *Lias* and the *Oölites* in England. Later the study of the Swiss Jura gave many additional facts regarding these rocks, and the name *Jurassic* was used as including all these scattered formations. The Swabian Alps of Germany present a very full set of these rocks, and a profusion of fossils in a wonderful state of preservation are found in France; so that "to-day the Jurassic is perhaps better known than any other similar system of formations." (Grabau.)

Subdivisions. The following are the divisions of the system as recognized in England, only a fraction of which have been worked out in this country so as to make a perfect correlation, though the general divisions, Lower, Middle, and Upper, are everywhere recognized:

Upper Jurassic or Malm	Purbeck Portland Kimmeridge Clay
Middle Jurassic or Dogger	Coral Rag Oxford Clay Kellaway Rock
Lower Jurassic or Lias	Great Oölite Inferior Oölite

Distribution. Outside of a few doubtful localities, as in New Jersey, no rocks of the Jurassic are found on the Atlantic border of the United States or Canada. But in Cuba, in Texas, and in the States of Puebla and Vera Cruz, Mexico, they occur, the beds in Mexico being black and yellow clay slates.

On the Pacific coast, the Lias, or Lower Jurassic, is found in various parts of California, in Oregon, and especially in Alaska and some of the arctic islands. In the northern part of California, all three divisions of the system seem to be represented; while the gold-bearing veins of the Mariposa formation of the Sierra Nevada range, penetrating highly metamorphosed slates,

are regarded as Upper Jurassic. Extensive limestones and slates of the same classification are found in the Humboldt Range of Nevada.

A remarkable series of beds is found on the Arctic shore of Alaska, near Cape Lisburne, consisting of shales, sandstones, and a few conglomerates, with some 40 or 50 seams of a good

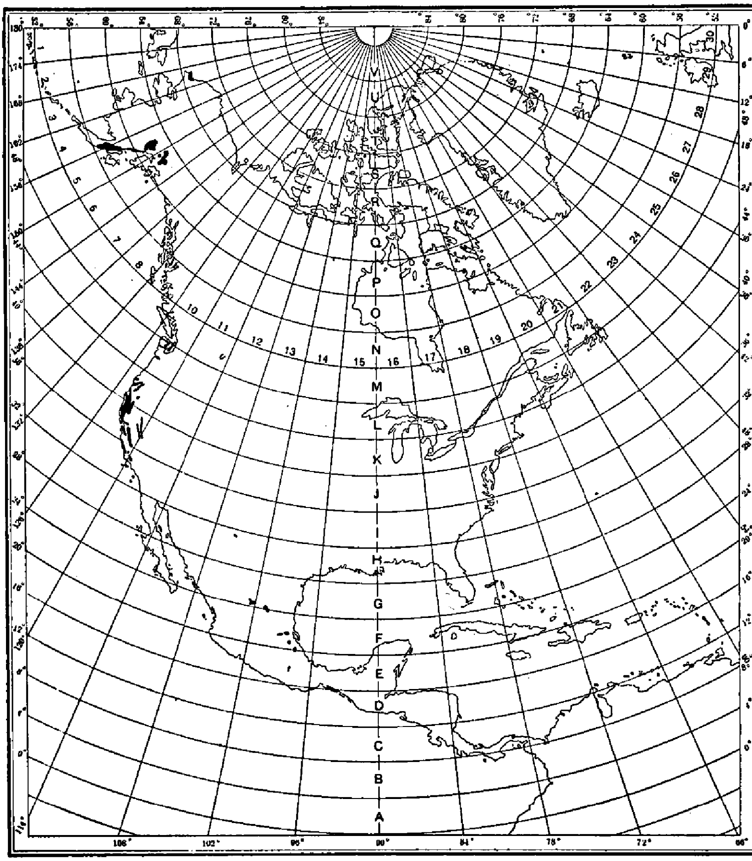

FIG. 310. Map showing the distribution of Jurassic rocks in North America.

grade of coal, the seams aggregating a total thickness of 137 feet. Ten of the beds are over 4 feet thick each, and one is 30 feet. The plants are the usual Jurassic flora of more southerly localities, and include the fronds of large fruiting ferns, and the leaves of the Ginkgo (Fig. 311), similar to the living Japanese variety, *Ginkgo biloba,* widely cultivated in the United States for its handsome fan-shaped leaves. Even palm leaves have been found in these now arctic rocks.

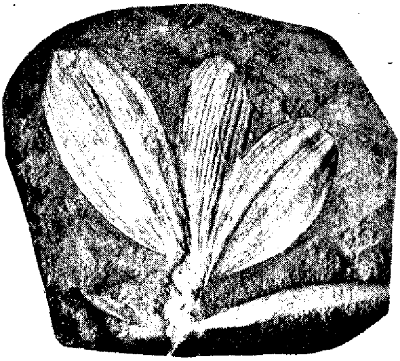

FIG. 311. Leaf of the Ginkgo, or maidenhair tree, very abundant in the strata from Oregon and Eastern Siberia, as well as at Cape Lisburne, Alaska. It is identical with the living Japanese tree, *Ginkgo biloba*, widely cultivated in the United States for its handsome fan-shaped leaves. (U. S. G. S.)

In Montana, Idaho, Wyoming, Utah, and Colorado are comparatively thin beds of clays, marls, impure limestones and sandstones, the fossils being almost universally oysters, with a few ammonoids and squids. They are classed as Middle Jurassic, and contain a few ichthyosaurs and plesiosaurs.

Farther south, in the Grand Cañon region, cross-bedded white sandstones often outcrop above the red underlying Triassic. These white Jurassic beds are locally called the *White Cliff*, being equivalent to what is termed the *La Plata* farther north and elsewhere. Fossiliferous shales and limestones, with occasional gypsum beds, occur in the high plateau region of Utah; but red beds classed as Jurassic, and associated with dark calcareous shales and shaly limestones, are

FIG. 312. East side of East Fork, Sandcoulee, Montana, showing Jurassic sandstone lying directly upon Madison limestone (L. Carboniferous). Here the Middle and Upper Carboniferous, the Permian, and the Triassic are wanting; yet these two sets of strata are essentially parallel with each other, and seem to have followed one another in quick succession. (Fisher, U. S. G. S.)

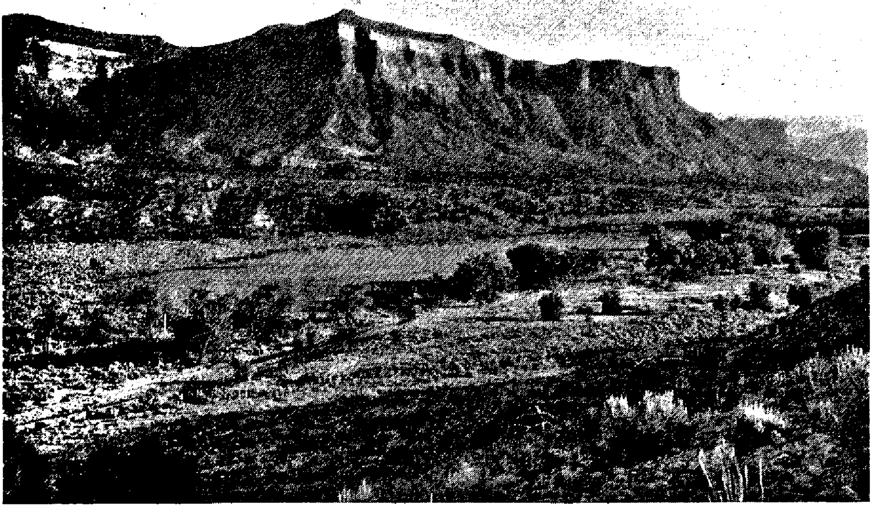

FIG. 313. Looking across West Creek, about 3 miles east of Dolores River, Colorado. The light-colored band at the top of the cliffs is the La Plata (Jurassic) sandstone. Beneath occur the Dolores (Triassic) and the Cutler (Permian) formations. The valley of the Dolores River is seen on the extreme right. (Cross, U. S. G. S.)

found on both sides of the Front Range of the Rocky Mountains, and similar beds occur as far east as the Black Hills and the Big Horn Mountains. The most characteristic fossils of these beds are certain varieties of *belemnites*, several pelecypods, *Trigonia* of many species, some crinoids with five-sided stems, and a few ichthyosaurs. (Grabau.)

These typically marine beds are followed by a remarkable series called the *Morrison*, which has occasioned much controversy among geologists as to whether they are properly Jurassic or Cretaceous. These beds contain such a profuse assortment of dinosaurs and mammals, with land plants and fresh-water invertebrates, that it has been very difficult to assign all the beds to either the one system or the other. The Morrison beds "extend down the eastern front of the Rocky Mountains from Wyoming to Texas and New Mexico, with disconnected areas, perhaps outliers, in the Black Hills and Western Colorado." (Scott.) The name *Morrison* is from a place of the same name near Denver, where these beds were first examined and specimens of dinosaur bones collected in 1877. Subsequently even more important discoveries of dinosaurs were

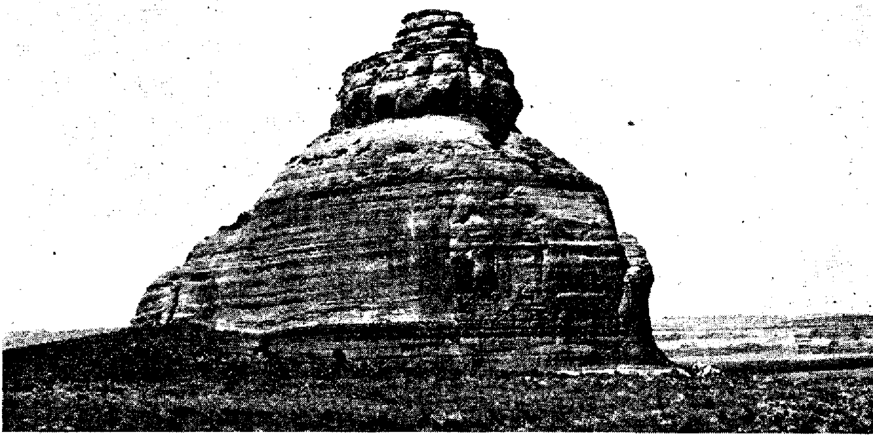

FIG. 314. An outlier, called "Casa Colorado," composed of La Plata (Jurassic) sandstone. Dry Creek, Utah. Looking north. (Cross, U. S. G. S.)

made at Como Bluff, near Medicine Bow, Wyoming, with the result that now almost every large museum in this country has some specimens from these dinosaur bone yards.

Foreign. As already intimated, the Jurassic system is very well shown in various parts of Europe. Fossils similar to those of the Black Hills of South Dakota are found in England, through Russia and Siberia, to Spitzbergen and Nova Zembla.

FIG. 315. Bluff on the east side of Oil Creek, 8 miles north of Cañon City, Colorado, showing Morrison, Comanche, and Dakota formations. (Stanton, U. S. G. S.)

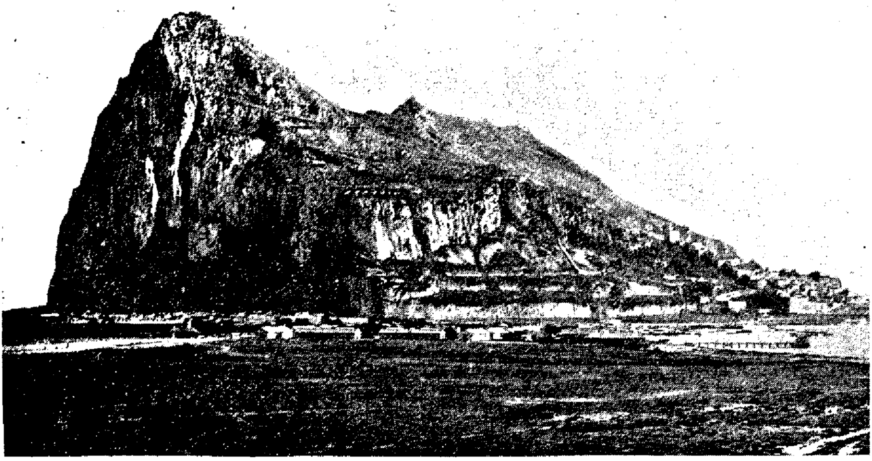

FIG. 316. The rock of Gibraltar. It is composed of Jurassic limestone, greatly eroded.

Jurassic beds are known from the Himalayas; and in India, the upper part of the *Gondwana series* is classed as Jurassic, as is also the upper part of the *Karoo beds* of South Africa. Coal beds of the Jurassic are found in the interior of Australia, while marine beds occur in New Zealand; but in South America, they seem to be confined to a narrow strip along the western coast. Here, however, we find some of the identical fossils that are characteristic of the Jurassic in Europe; "even the minuter divisions, the substages and zones of the European Jura, are applicable to the classification of the South American beds." (Scott.)

Life

Abundance. So many of the Jurassic strata show a profusion of fossils, often in a marvelous state of preservation, that nearly 15,000 species have been listed and described from them in Europe alone. Although only about one twenty-fifth as many (600) have been described from the American Jurassic, this great difference is not wholly or perhaps mainly due to any such actual difference between the beds in these two parts of the world, but is more largely due to the long and careful study which has been given to these rocks in the Old World.

Plants. As a whole, the Jurassic flora is much like that of the Triassic, consisting principally of ferns, horsetails, cycads, conifers, and gingkos. Forty species of cycads have been found in a single horizon of the English Upper Jura, while araucarian

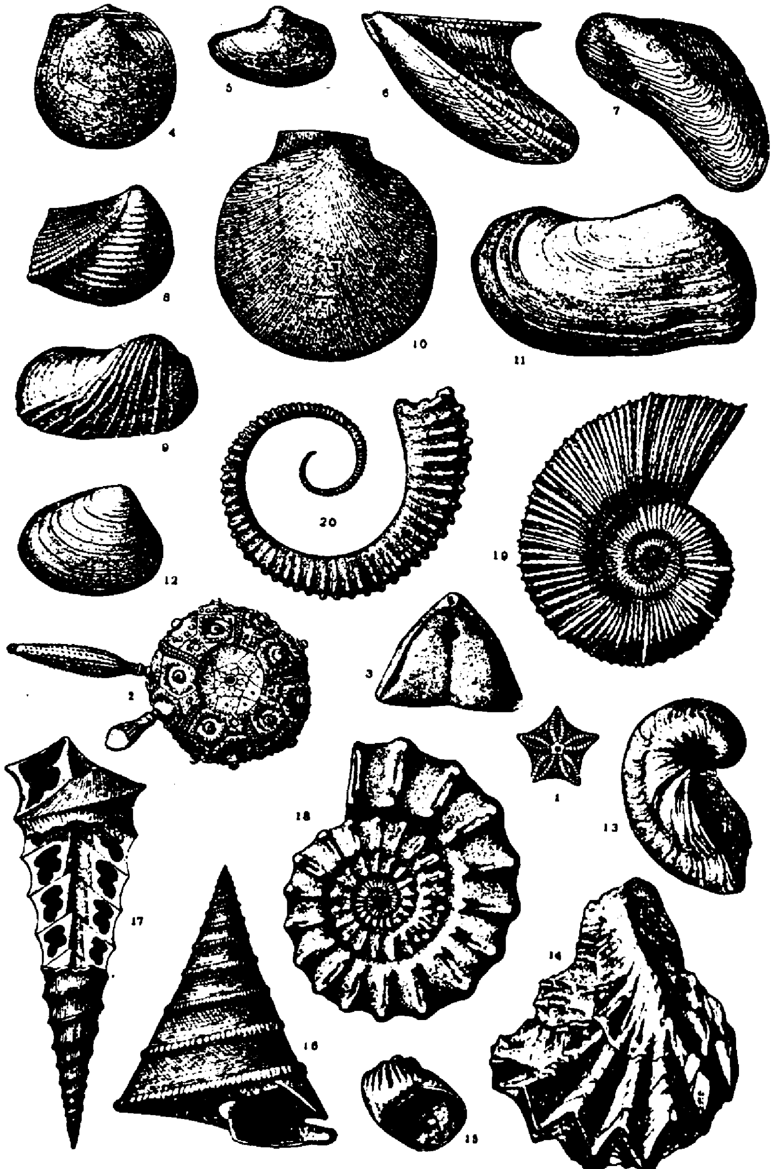

Fig. 317. JURASSIC INVERTEBRATE FOSSILS

1, *Pentacrinus asteriscus*, M. and H., section of stem, × 2, U. J. 2, *Cidaris coronata*, Goldf., × ½, Kimmeridgean, Europe. 3, *Antinomia catulli*, Pictet, × ½, Tithon., Alps. 4, *Eumicrotis curta*, Hall, × 3/2, U. J. 5, *Tancredia corbuliformis*, Whitf., × 1, U. J. 6, *Gervillia montanænsis*, Meek, × ½, U. J. 7, *Volsella subimbricata*, Meek, × ½, U. J. 8, *Trigonia americana*, Meek, × ½, U. J. 9, *Pholadomya kingi*, Meek, × ½, U. J. 10, *Camptonectes bellistriata*, Meek, × ½, U. J. 11, *Pleuromya inconstans*, Aguilera and Costello, × ½, U. J. 12, *Myacites subcompressus*, Meek, × ½, U. J. 13, *Gryphæa arcuata*, Lam., × 2/5, Lias, France. 14, *Ostrea marshi*, Sowerby, × 3/8, Bajocian, Germany. 15, *Lyosoma powelli*, White, × ½, U. J. 16, *Pleurotomaria conoidea*, Deshayes, × ½, France. 17, *Nerinea dilatata*, d'Orb, × ½, France. 18, *Peltoceras cf. athleta*, Phillips, × ¼, Callovian, Europe. 19, *Lytoceras fimbriatum*, Sowerby, × ¼, Lias, England. 20, *Crioceras bifurcatum*, Quenstedt, × ½, Bathonian, Germany. (After W. B. Scott, "Introduction to Geology," permission of Macmillan Co.)

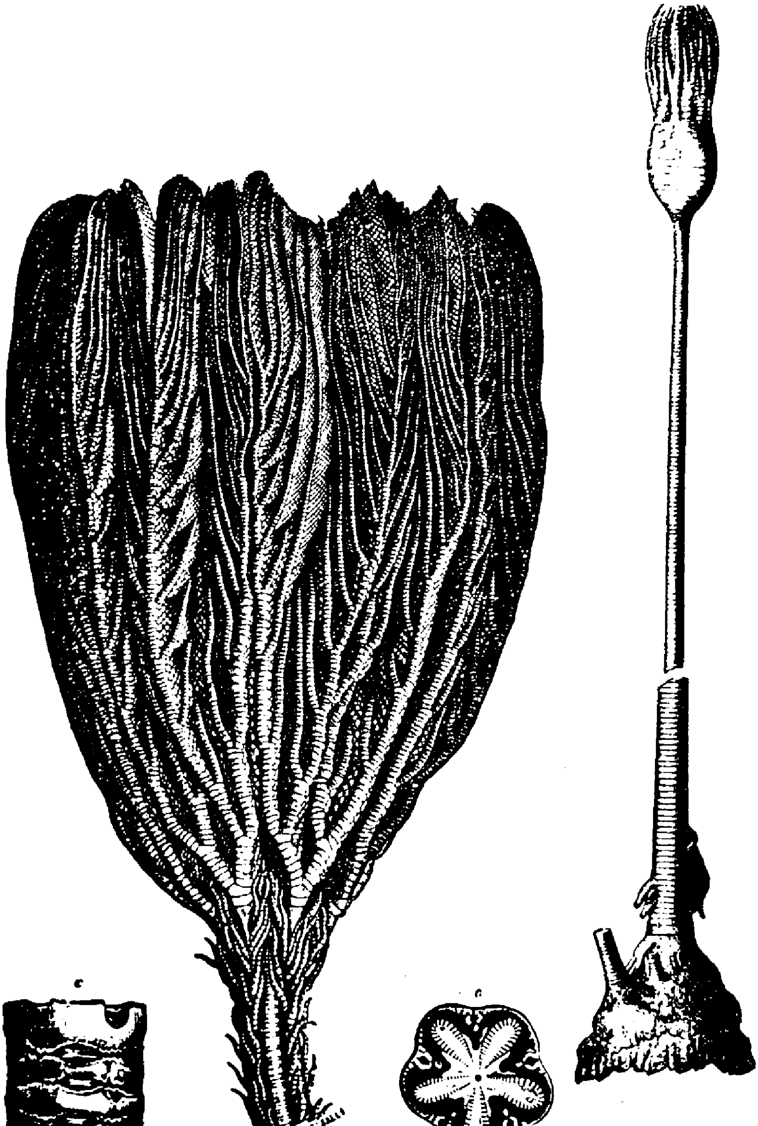

FIG. 318. Jurassic crinoids. *Pentacrinus fasciculosus*, showing calyx with arm and part of stem. *c*, *c*, lateral and summit view of stem points. (After d'Orbigny.) *Apiocrinus roissyanus*, showing entire individual. The stem has been shortened. (After d'Orbigny.)

pines also occur in England and throughout Europe. Of the conifers, such modern families as *arbor vitæ, cypress, yew*, and *pine* are also found in these rocks. The gingkos, or maidenhair trees, are also present in almost all localities where these rocks are well represented.

Invertebrates. *Foraminifera* occur in great numbers and in much variety, "many of them belonging to genera which still abound in the modern seas." (Scott.) Portions of the Austrian Alps consist of red flints and jaspery slates composed almost entirely of the tests of *Radiolaria,* quite like the modern kinds which now compose the deep-sea radiolarian oozes from two to four miles down in the ocean. In these Alps, the strata containing these radiolarians rest on variegated ammonite limestones or breccias, and are capped by other gray calcareous shales. (Grabau, "Principles of Stratigraphy," p. 459.) Radiolarian tests occur in many of the other Jurassic rocks found elsewhere.

While sponges have not been found in any great numbers in the preceding systems, they are very plentiful in some of the Jurassic beds, and their most minute structure can often be seen in detail under the microscope. "In some localities these sponges are heaped up in such masses that they fill the strata,

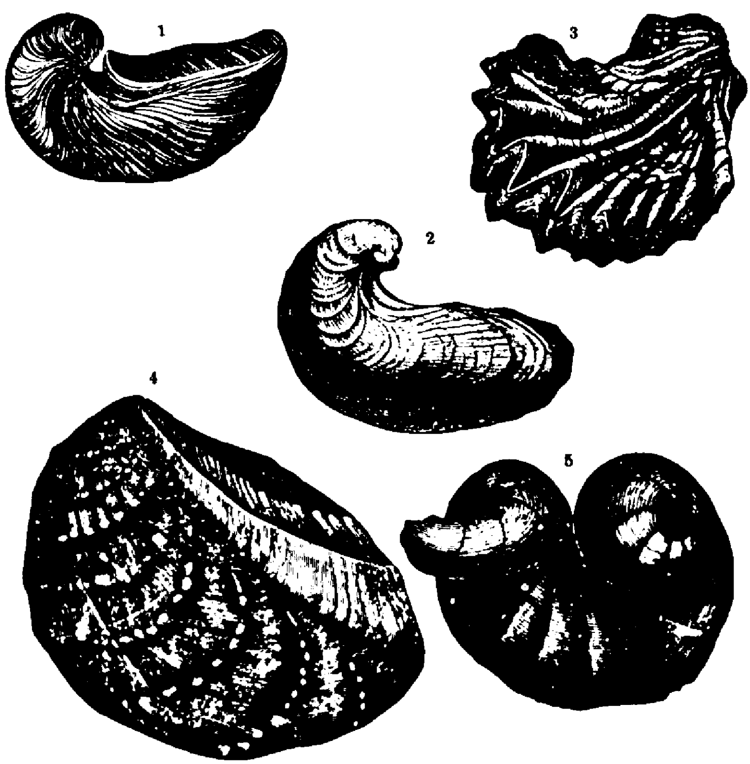

FIG. 319. Jurassic mollusks. 1, *Gryphæa incurva;* 2, *Exogyra virgula;* 3, *Ostrea marshii;* 4, *Trigonia clavellata;* 5, *Diceras arietinum.* (After Dana.)

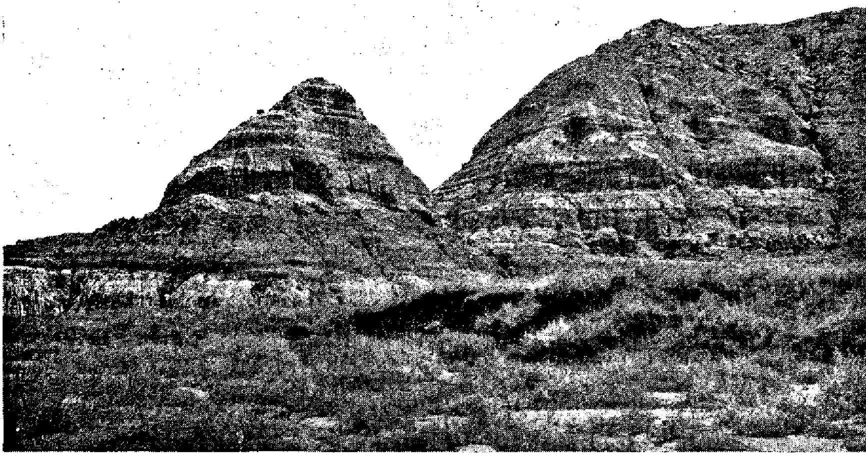

FIG. 320. North end of Cedar Butte, near Wade, North Dakota. Lance formation (? U. Cretaceous). (Stanton, U. S. G. S.)

while other localities of the same horizon are entirely free from them." (Scott.)

Anthozoan corals, belonging to the living Hexacoralla, are common in the limestones of England and Central Europe.

The *crinoids* are again found in great profusion, though there are few of them in the preceding Triassic. In number of species and genera, the crinoids of the Jurassic do not equal those of the Carboniferous; but in point of size, as well as in the abundance of individuals, the Jurassic is superior to all other formations. Especially characteristic are the giant members of the genus *Pentacrinus*, similar to those which still live in the waters off the West Indies and in the Pacific Ocean. Some of the fossil members of this group had stems 50 feet long, with a crown a yard in length and in width. Sea urchins, starfishes, and brittle stars like the modern ones also occur.

Of the *Arthropoda*, many crustaceans are occasionally found in particular localities, such as the clastic lithographic limestones of Solenhofen, in Bavaria; but as a rule, they are not very numerous. However, decapods, similar to our crabs and lobsters, are found. *Limulus*, the horseshoe crab, occurs as a fossil in many places in Europe; but the living ones are now confined to the eastern coast of the United States and the Molucca Islands.

Many varieties of *insects* are found in these rocks; but the higher orders, as the Lepidoptera, are not certainly known in these strata.

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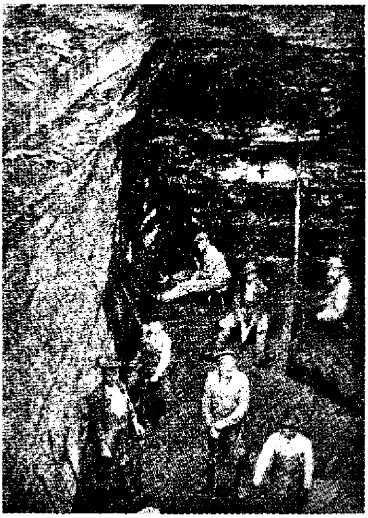

FIG. 321. Quarry in the slates of the Upper Lias (Jurassic), at Holzmaden, Württemberg, Germany. In 1911, more than 25 such quarries were in operation in this vicinity. About 100 specimens of saurians are obtained each year from these quarries, about ten per cent of which are sufficiently perfect to warrant preservation. (After Grabau, and Bernard Hauff, Holzmaden-Teck, Germany.)

Brachiopods occur, but they are not characteristic; and they are chiefly represented by genera which are still alive in our modern seas.

Bivalves like the oysters, such as *Gryphæa, Exogyra,* and the great order *Ostrea,* often form great banks and strata almost alone. The genus *Trigonia* is considered to be quite distinctive of the Jurassic beds; but living representatives of the genus have been discovered in the seas near Australia. Gastropods like the living *Purpurinæ* and the *Pleurotomaria* are also found in the Jurassic, but are not regarded as "index fossils" of these rocks.

But the *Cephalopoda* reach their "culmination" in these Jurassic formations, "filling whole strata with their heaped up shells." (Scott.) Both the nautiloid and the ammonoid group are represented by a profusion of species and of individuals. But even more characteristic of these strata are the *belemnites,* which more nearly resemble the modern squid or cuttlefish. They had a straight, conical, chambered shell, which was partly external to the animal, its sharp end being covered with a sort of cap of dense calcite, called the *guard,* or *rostrum.* Great numbers of the latter have been preserved as fossils, and have been called the "thunderbolts of Thor," from which the name *belemnite* is derived, coming from the Greek word for dart. The various kinds of ammonites and belemnites are regarded as splendid "index fossils" by means of which to distinguish the different subdivisions of the Jurassic.

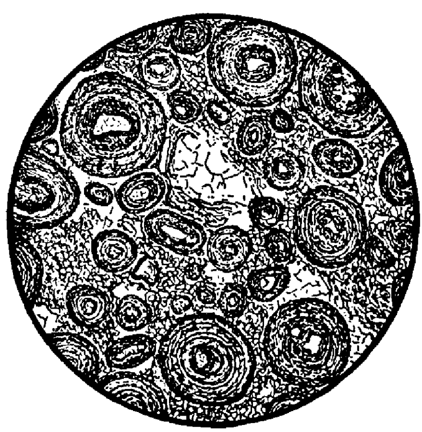

FIG. 322. Microscopic section of Jurassic oölite, showing the zonal or concentric structure of the grains. Enlarged 24 diameters. (After Rosenbusch.)

FIG. 323. Oölitic limestone silicified. (Photograph by B. Hubbard.)

Vertebrates. Of the fishes, sharks and rays are found in practically their modern forms. *Chimæroids,* like the bizarre types which live in our modern deep seas, are often found; but the dipnoans are represented only by the living genus *Ceratodus.* Ganoids much like our modern sturgeons and gar pikes are found, some of them being very large. "Some of the Jurassic fishes approximate the teleosts so closely that it seems arbitrary to call them ganoids." (Scott.)

"No Amphibia are certainly known from the Jurassic." (Scott.) Comment is unnecessary.

But the *reptiles,* by their great numbers, their astonishing variety of forms, and their monstrous size, quite make up for the absence of the Amphibia. *Rhynchocephalia,* lizards, and turtles are common; but the *ichthyosaurs,* or fish-lizards, are especially plentiful. "Certain localities in the Lias of England and Germany have yielded an incredible number of skeletons, and some of the specimens have preserved the impressions of the outline of the body and limbs, showing recognizably the nature of the skin." (Scott.) Some of these water reptiles were 25 feet or more in length, and must have looked almost exactly like the modern dolphins and porpoises, though this resemblance would have been wholly superficial, the latter being neither fishes nor reptiles, but true warm-blooded mammals. The evolutionists call it a remarkable case of "parallel development," when such very different creatures resemble one an-

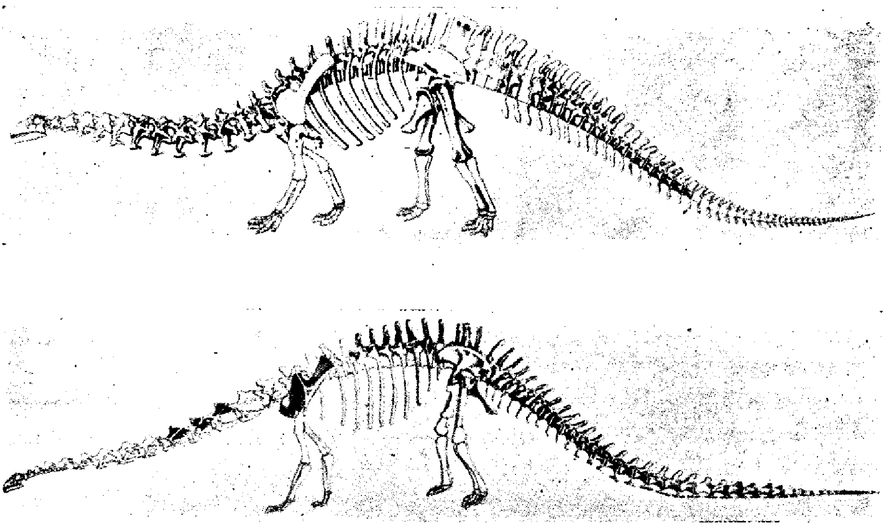

FIG. 324. Skeletons of *Brontosaurus* (above) and *Diplodocus* (below) in the American Museum of Natural History, New York City. The parts preserved in these specimens are shaded. Scales, 10 feet — 1 inch. (After W. D. Matthew.)

other outwardly in this way; but there are almost innumerable cases of such "parallel development" all through the plant and animal kingdoms.

The *Plesiosauria* were another group of marine, carnivorous reptiles, with small heads, but with long necks and tails, and with enormous paddles or flippers, two on each side. They were some 20 feet long; but very much larger "sea serpents" occur in the Cretaceous.

Crocodiles closely resembling the living gavial of India are very plentiful.

Gigantic *dinosaurs,* like *Brontosaurus* and *Diplodocus,* 60 feet or more in length, have been found in the Morrison beds of the western United States. They were the most enormous creatures which ever walked on dry land, almost rivaling the whales in size. They will be considered more at length in a subsequent chapter.

Flying reptiles, or *Pterosauria,* are also found, with a curious kind of bird (Archæopteryx), the skeletons of two of which have been preserved in the limestones of Solenhofen. This creature had a full set of teeth, and a long vertebrated tail; and of course the evolutionists point to these characters as visible relics of its reptilian ancestry.

A very few small, insignificant *mammals* have been found in Jurassic beds from here and there all over the world; and

they are looked upon with great interest by those who believe in the development theory, and who believe that these Jurassic beds are actually older than the Cretaceous and Tertiary formations, where the majority of the mammals are found.

Unscientific Methods. According to the curious methods of reasoning hitherto in vogue in paleontology, if any large, well-

FIG. 325. *Archæopteryx lithographica,* from the lithographic limestone series of the Solenhofen region, Bavaria. Specimen in Berlin Museum. Reduced.

organized mammals should happen to be found in any given set of beds, this very fact would prove that these beds could not possibly be Jurassic.

This method of reasoning is correct enough, if we recognize these geological classifications as merely taxonomic classifications; but it is hard to understand how men with any mental training can take the *results* of such a constructive arrangement of the fossils as the historic outline on which to construct evolutionary trees of descent. The history of human thought presents nothing more remarkable or more pathetic than the prevalence, for over half a century, of such methods of tracing out alleged evolutionary pedigrees, and doing all this in the name of natural science and under the ægis of its protective name.

CHAPTER XXXIII

The Cretaceous System

History. The Cretaceous (Latin, *creta,* chalk) rocks get their name from the soft limestone called *chalk* found in the south of England and the north of France. But as with all the other systems, these Cretaceous rocks in other localities are not

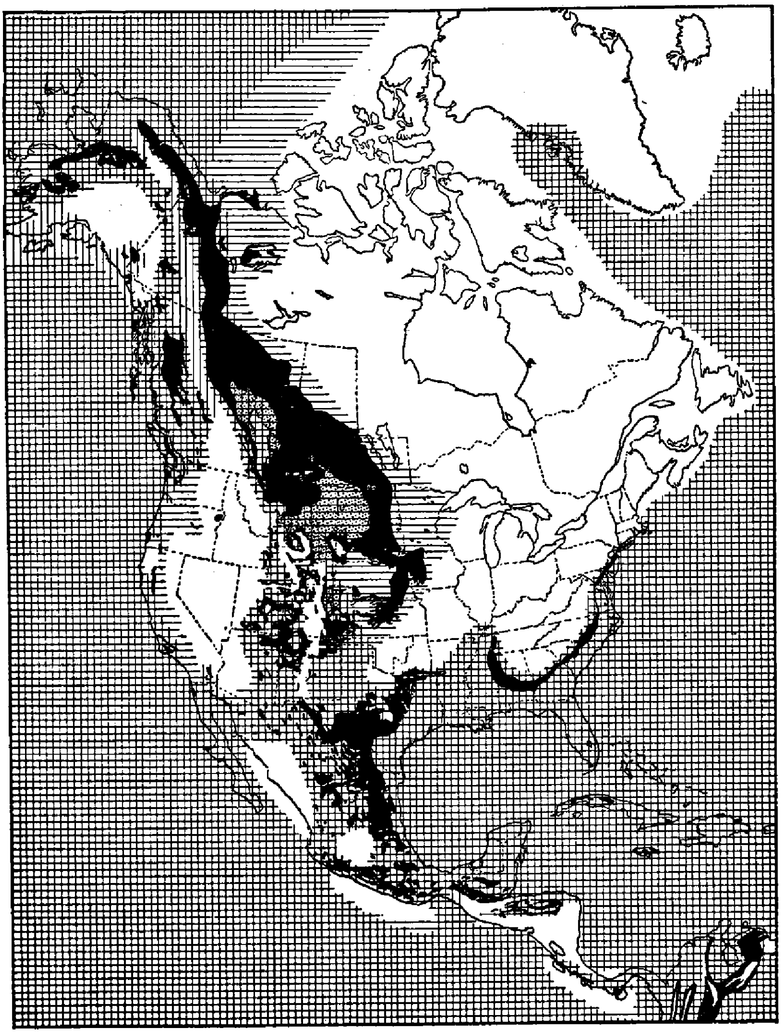

FIG. 326. Map of the Cretaceous areas of North America. Black areas indicate known exposures. (After W. B. Scott, "Introduction to Geology," permission Macmillan Co.) It will be noted that Cretaceous rocks cover much wider areas than do those of any other formation.

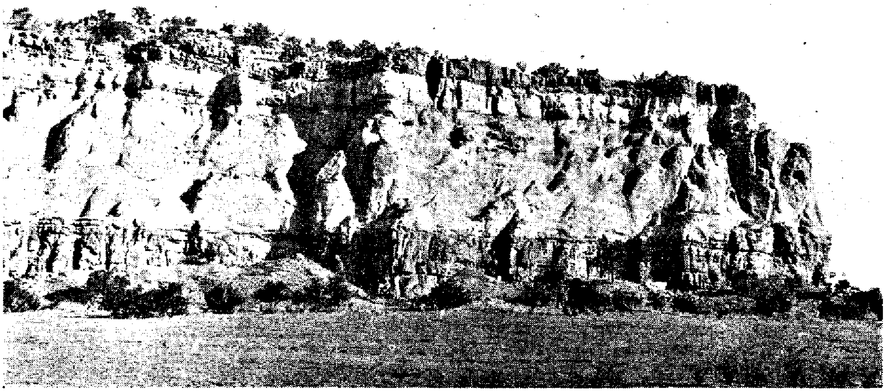

FIG. 327. Cretaceous sandstone on Red Beds (Permian), south of Zuni, New Mexico. (Darton, U. S. G. S.)

by any means entirely, or even largely, composed of chalk, but consist of hard limestones, sandstones, shales, and conglomerates. Quite frequently they comprise soft beds of sand, clay, or shells "so imperfectly consolidated that they may be turned up with a pick." (Dana.) In England, sands colored green from *glauconite* were early examined by William Smith and his contemporaries, and these were called the *Greensands;* later even this name began to be applied to beds with similar fossils which might be composed of very different materials from the original glauconitic sands. In fact, *all such names are used in geology as mere names, and not as descriptions of the lithologic structure of the beds.* Of late, the more convenient custom has been adopted of giving to the formations geographical names derived from the localities where the formations were first observed or typically developed.

Subdivisions. But the standard for the details of this system has been worked out in France and Switzerland, rather than in England. In Europe, two great subdivisions are recognized, the Upper Cretaceous and the Lower Cretaceous. In America, the lower of these divisions is usually called the *Comanchean,* a name derived from that of the Comanche Indians, who used to live in the regions of Texas and Mexico where these rocks were found to be well represented. Thus in America we have (in ascending order) the *Comanchean* and the *Cretaceous proper,* the latter being subdivided into an Upper

and a Lower. This confusion of names gives rise to considerable inconvenience; but at present, it seems to be without remedy. The name *Neocomian* is used in England as equivalent to their *Lower Cretaceous,* and nearly synonymous with the American *Comanchean.*

In America, the subdivisions most widely recognized are as follows:

Cretaceous Proper	Upper Cretaceous or Laramie	
	Middle Cretaceous or Montana	Fox Hills Pierre
	Lower Cretaceous or Colorado	Niobrara Benton Dakota
Comanchean	Upper Comanchean or Washita	
	Middle Comanchean or Fredericksburg	
	Lower Comanchean or Trinity	

Distribution. In marked contrast with the scanty occurrence of the Triassic and especially of the Jurassic rocks in North America, the Cretaceous strata cover enormous areas of this continent.

A very complete set of the *Comanchean series* has been worked out in the States of Vera Cruz and Puebla, Mexico,

FIG. 328. Contorted beds of the Potomac (L. Cretaceous or Comanchean of the Atlantic) formation, resting on crystalline schists (Archæan), Belt Line R. R., Baltimore, Maryland. (Darton, U. S. G. S.)

where the series seems to begin with a great thickness of unfossiliferous slates which rest upon Jurassic or other rocks. These are often intercalated with marine limestones, and are followed by fossiliferous marls and limestones, the latter constituting the main limestone series of Mexico. Similar beds have been detected in Colombia and Venezuela; while to the north, similar limestones are seen in the southern half of Texas,

FIG. 329. Erosion remnants of Dakota sandstone (L. Cretaceous), in Monument Park, northwest of Colorado Springs, Colorado. (Darton, U. S. G. S.)

and extending through the western mountains of this State to Bisbee, Arizona. The twisted pelecypod, *Requienia,* is one of the index fossils of these formations (*Trinity*).

A characteristic basal sandstone underlies not only these rocks of the Trinity division, but also "the whole Comanchean series in the southern United States." (Grabau.) It is supposed to be continuous to the north with the so-called basal *Dakota sandstones.* The limestones overlying these beds at Austin, Texas, and on the Rio Grande, are marked by the presence of the odd-shaped rudistid pelecypods, *Monopleura, Radiolites,* and other similar forms, these fossils being duplicated in the Lower Cretaceous beds of Southern Europe. Northward these beds are represented by sandstones in Southern Kansas,

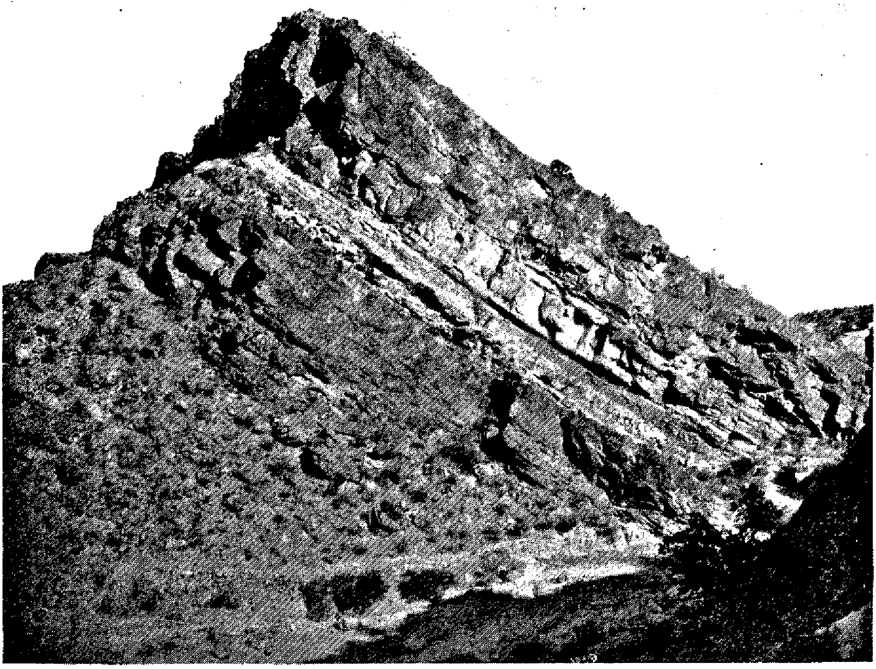

FIG. 330. Hogback, 2 miles southwest of Cañon City, Colorado. Composed of Dakota beds (L. Cretaceous), with Morrison strata to the left (U. Jurassic), and Niobrara (L. Cretaceous) to the extreme right. (Darton, U. S. G. S.)

FIG. 331. Cliffs of Niobrara limestone (L. Cretaceous), on the Missouri River, above Running Water, South Dakota. Taken from the ferry landing, on the Nebraska side of the river. (Stanton, U. S. G. S.)

which contain plant remains, and which are overlaid by beds containing *Gryphæa, Exogyra, Ostrea,* and other kinds of oysters.

The *Washita* shales and limestones cover large areas of Kansas and Oklahoma; while far to the north, the *Kootenai* coal beds of Southeastern British Columbia and Alberta are considered to be equivalents. These immense coal deposits in the Kootenai area proper and around Crowsnest Pass are estimated to cover an area of 3,000 square miles, and contain nearly 8,000,000,000 tons of coal, 400,000,000 tons of which can be classed as real anthracite. Similar coal beds of more limited thickness are found near Great Falls, in the central part of

FIG. 332. Mesa capped by Niobrara limestone (L. Cretaceous), Arkansas Valley, Eastern Colorado. (Gilbert, U. S. G. S.)

Montana; and very thick seams have also been observed in the North Fork of the Flathead, to the west of the Glacier National Park. Both on the east and on the west of these mountains of the Glacier National Park, the flat-lying Cretaceous shales underlie the massive Algonkian limestones and quartzites composing the greater part of the front ranges of the Rockies, such outliers as Chief Mountain, just to the south of the international boundary line, and Crowsnest Mountain, lying in apparent perfect conformability on the Cretaceous beds, though they are themselves composed of Paleozoic rocks. In fact, as Cretaceous beds seem to underlie the mountains of the Glacier National Park on all sides, the park might be spoken of as a huge Paleozoic island floating on a Cretaceous sea. The obvious contradiction to the traditional order of the rocks needs no comment.

The Cretaceous of the Pacific coast is subdivided as follows:

Cretaceous or Chico series
  Thin-bedded and massive sandstones and conglomerates
Comanchean or Shasta series
  Horsetown beds
    Thin-bedded sandstones and shales
  Knoxville beds
    Shales, calcareous layers, with sandstones below

While these names are derived from the occurrence of the Cretaceous in California, similar formations have been described in Oregon and in British Columbia. In the latter prov-

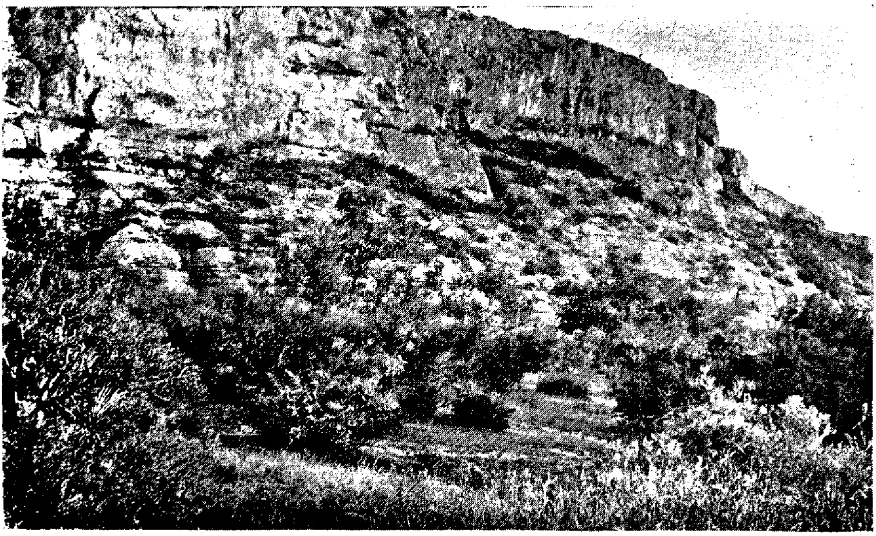

FIG. 333. Cliff of Washita limestone (L. Cretaceous), on Devil's River, at the mouth of Rough Cañon, Texas. The beds contain ammonites, echinoids, etc., at base, and Caprinidæ at top. (Stanton, U. S. G. S.)

ince, these beds contain not only extensive coal beds, but also beds of iron ore. Northward in Alaska, they also contain coal. The fossils of the Chico and the Horsetown beds are similar to those of the equivalent beds in India, while the Knoxville fossils are more like fossils found in the far north of America.

Beds of the *Comanchean series* are extensively spread out over the Great Plains regions of America from Montana south into New Mexico, if we assume that the *Morrison series* are chiefly to be classed with the Cretaceous system. But beds of the Cretaceous proper (Upper Cretaceous of Europe), called the *Dakota formation,* are found in many places to the east and also to the west of the Front Range of the Rockies. In the Uinta

FIG. 334. Erosion forms in Dakota sandstone (U. Cretaceous), 5 miles east of Kenton, Oklahoma. Note the cross-bedding in the strata. (Gould, U. S. G. S.)

and Wasatch Mountains, the Dakota strata rest in "apparent conformity" upon the Jurassic, though the whole of the Comanchean is there wanting. (Scott.)

The extensive chalk deposits of Kansas are placed in the *Niobrara formation,* as are also the beds regarded as equivalent in South Dakota. Harder limestones and even sandstones are associated with these beds.

Coal beds in Alberta are listed as belonging to the *Montana* formation; but the most extensive coal deposits of these Cretaceous rocks are classed as belonging to the *Laramie,* though some geologists consider that some of the beds of this formation should be classed as belonging, not to the Cretaceous, but to the first part of the Tertiary.

It should be remembered that these strata of the Rocky Mountains and Great Plains are spread out over a very wide territory, that great areas of this region are difficult of access and have not been extensively studied, and moreover they are largely detached from one another, so that stratigraphical correlation is usually impossible, and therefore dependence is placed almost wholly upon the fossils. The latter are plentiful

enough in many localities; but the lack of careful examination has led to hasty generalizations about the extent of many of these individual formations, and it may be that some of the formations which are now supposed to be of almost continental extent will ultimately prove to be repeatedly interrupted by other kinds of deposits.

On the Atlantic coast, the *Potomac* (*Comanchean*) formation is found in isolated patches from Martha's Vineyard, Long Island, through New Jersey southward to Georgia. Here these beds are traced westward (with interruptions) through Tennessee and Arkansas. In Maryland, where these rocks are best developed, are some dark carbonaceous shales carrying beds of lignite, in which have been discovered some seven skeletons of dinosaurs, a fact which has been the means of correlating these beds with the Morrison beds of the Great Plains. Along much of the Atlantic border are also beds of the Upper Cretaceous, the materials of which "are unconsolidated, and consist in the lower half of gravels, sands, and clays with lignite, while the upper portion is made up of clays and sands becoming more and more glauconitic and finally going over mainly into greensands." (Schuchert.) "Cretaceous formations that are practically unconsolidated are met with from Tennessee through Eastern Mississippi into Alabama and Georgia. Nearly

FIG. 335. A cliff of Benton limestone (Cretaceous), near Thatcher, Colorado. The pelecypod, *Inoceramus labiatus*, occurs here in great abundance. Note the alternation in the beds. (Gilbert, U. S. G. S.)

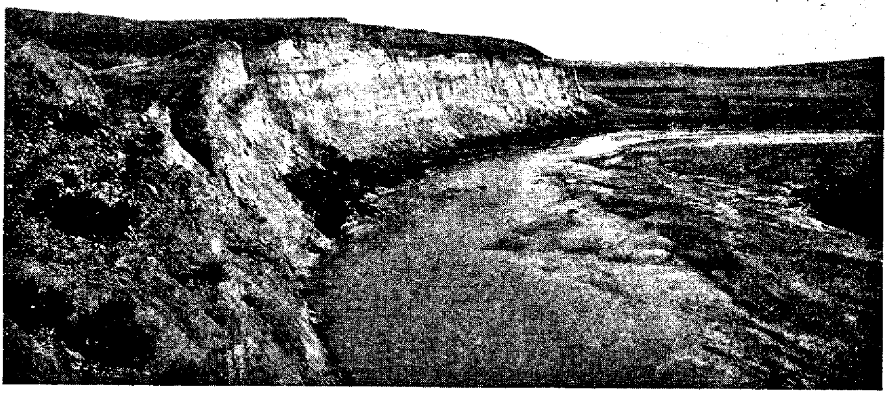

FIG. 336. Little Missouri River, with Fox Hills sandstone (U. Cretaceous) showing in the cut bank, capped by Lance formation (? U. Cretaceous). (Hares, U. S. G. S.)

everywhere they overlap Paleozoic strata, and in Georgia they rest on the more ancient crystallines." (Schuchert.)

Another widely scattered area of Cretaceous rocks is found in the West Indies, where the strata consist often of basal arkose sandstones which are unfossiliferous, or coal-bearing

FIG. 337. Eutaw formation (U. Cretaceous), with about 2 feet of superficial material on top; in a railway cut, near Leidy, Mississippi. (Shaw, U. S. G. S.)

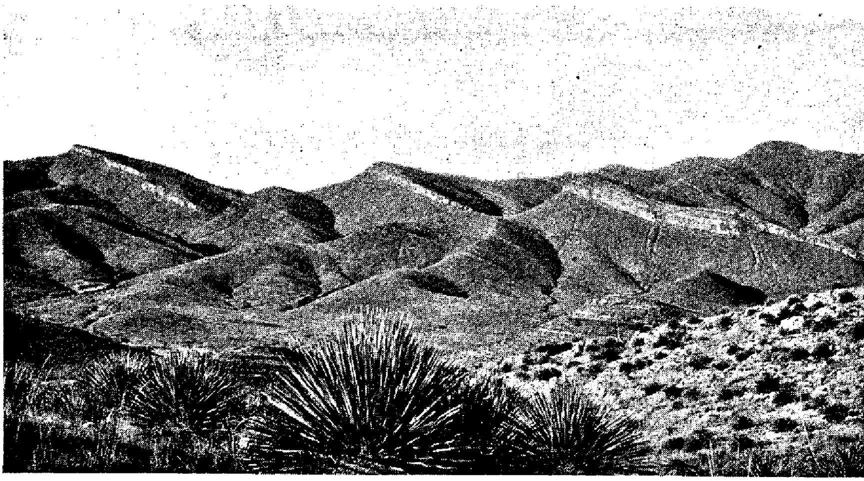

FIG. 338. Hills of Cretaceous strata, west of Bisbee, Arizona. (Ransome, U. S. G. S.)

beds followed by shales and limestones with marine fossils. We have found this order a very common one; and it is instructive that in some instances at least, as at Havana, Cuba, and in Jamaica, the bottom of the series rests *directly upon the old crystallines* or the *Archæan.* (Grabau.) On Porto Rico, some of the beds abound in Foraminifera, though thick-shelled *Rudistes* and other shallow-water pelecypods are associated with them, as are also sandstones and other clastic rocks.

Foreign. In England, the *Wealden* formation has been correlated with the Morrison of America, because it also contains the remains of large dinosaurs in great numbers. This formation is extensively developed in the south of England, and consists of sands and clays in which are the remains of plants and the shells of such species as *Unio, Paludina,* and others found in fresh water. Beds regarded as equivalent occur in Northeastern Spain, in Germany, and in Poland, coal occurring in the latter countries.

The more distinctively marine deposits of the Upper Cretaceous are widely spread over Europe and the northern part of Africa. But they are almost wholly *absent from the eastern part of Asia.* Indeed, as one veteran geologist has remarked, "A geologist taught only by observation in China, outside of Tibet, would know nothing of the Cretaceous. No strata are known which may be correlated with the strata that represent the period in America and Europe." (Bailey Willis.) They are known, however, in India, Australia, and South Africa.

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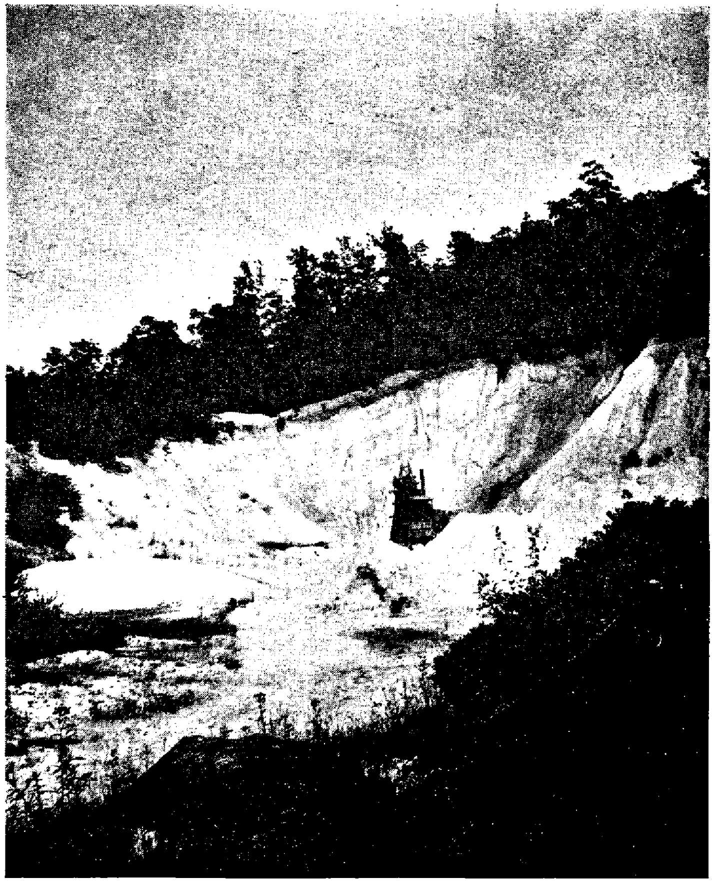


FIG. 339. White Cretaceous clays and sands, near Sea Cliff, Long Island, New York. Worked for the sand. (Fuller, U. S. G. S.)

But these marine deposits often contain coarse sands or even conglomerates, much of the Carpathian Mountains being of this character (*Flysch* formation). Near Dresden, these beds rest directly upon the old crystalline rocks, and contain well-preserved brachiopods, oyster shells, and sponges.

The Chalk. The *chalk* itself, which has given its name to the system, is splendidly shown in the white cliffs facing the Dover channel on both the English and the French coast (Fig. 341). It consists of fine calcareous particles which the microscope shows to be composed chiefly of the minute shells of Foraminifera, similar to those now composing the foraminiferal oozes at the bottom of the Atlantic. Calcareous plates called *coccoliths*, probably due to unicellular algæ, are found among

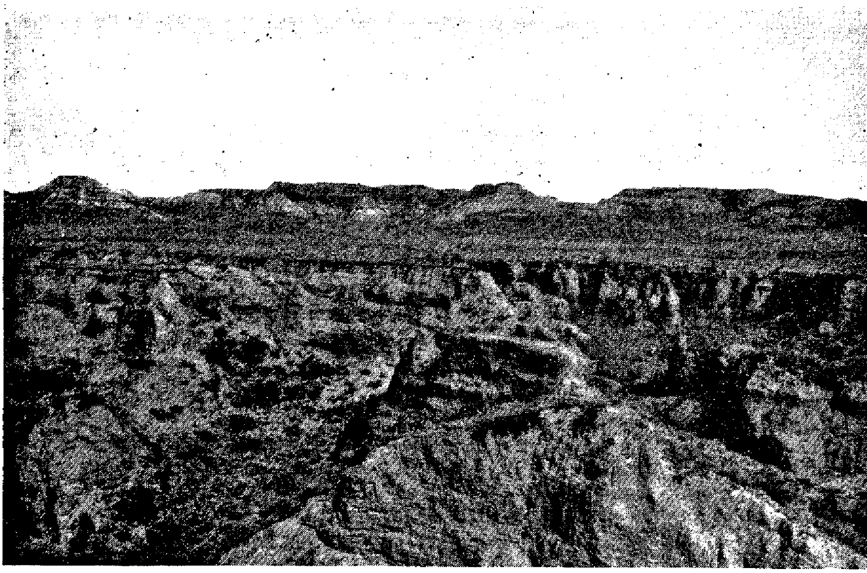
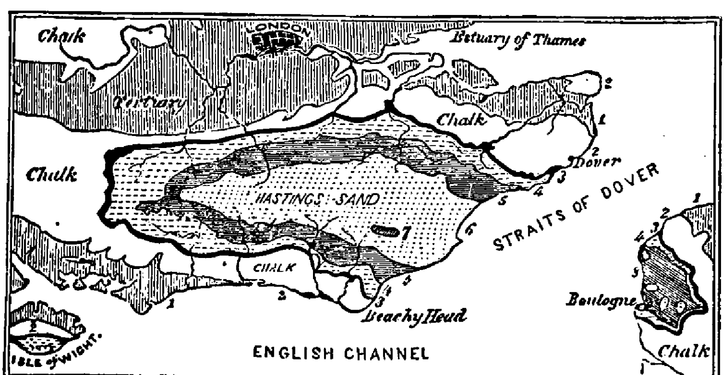


FIG. 340. The hills in the distance are composed of the lignite-bearing member of the Lance formation (? U. Cretaceous). Little Missouri River. Erosion of alluvium in the foreground. (Hares, U. S. G. S.)

the chalk; and the siliceous spicules of sponges, "and probably to some extent radiolarian shells as well" (Grabau), are also scattered through the chalk. The percolating waters have dissolved some of these siliceous particles, and have redeposited



1. Tertiary.
2. Chalk and upper greensand.
3. Gault.
4. Lower Greensand.
5. Weald clay.
6. Hastings sands.
7. Purbeck beds.
8. Oölite.

FIG. 341. Geological map of Southeastern England and part of France, exhibiting the denudation of the Weald. (After Lyell.)

FIG. 342. The Sphinx, cut from a ledge of nummulitic limestone (Cretaceous), surrounded and formerly partly buried by desert sands derived largely from the destruction of a sandstone in other parts of the Libyan desert. The Great Pyramid in the background is covered by slabs of nummulitic limestone, the fossils which project by weathering being called "Pharaoh's beans," by the Arabs.

them at certain levels through the chalk in the form of bands of flint nodules. The shells of various pelecypods, the tests of sea urchins, and other fossils, are found at different horizons throughout the mass, which is quite distinctly stratified, and often has sands and shales or marls as the lateral extensions of the beds.

Ever since the first deep-sea explorations and the discovery of the modern foraminiferal oozes at the bottom of the oceans, it has been supposed that the chalk must have been of deep-water origin. Of late, however, some have argued that the organisms associated with the ancient chalk, as well as the fact that the chalk turns into clay or sand beds when traced sufficiently far laterally, indicate that it must have had a shallow-water origin. That it has passed through a shallow-water stage, goes without any argument; for it now has *no* water at all above it. But that it really *originated in the deep ocean,* there can be no doubt. The only question is whether it got from the bottom of the deep ocean to its present position above water by some *gradual,* ordinary process, or by some *extra-*

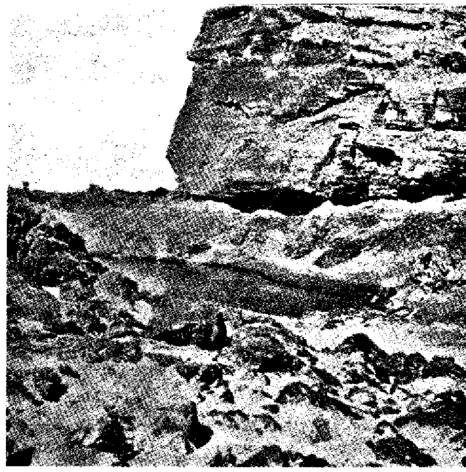


FIG. 343. Nubian sandstone (Cretaceous), near the Second Cataract of the Nile, Sudan. This is the rock from the disintegration of which the sands of the Libyan desert are largely derived.

ordinary one. On this point, probably one person's opinion might never convince another, since we have absolutely nothing to point to in the way of any similar occurrence which has gone on within scientific observation.

Life

Plants. The plants of the Lower Cretaceous (Comanchean) are much the same as those of the Triassic and Jurassic, and include ferns, horsetails, cycads, and numerous kinds of conifers. But the flora of the Upper Cretaceous is very different, and includes a wide variety of *dicotyledons* of a very "modern" appearance. In many widely separated parts of the world, such

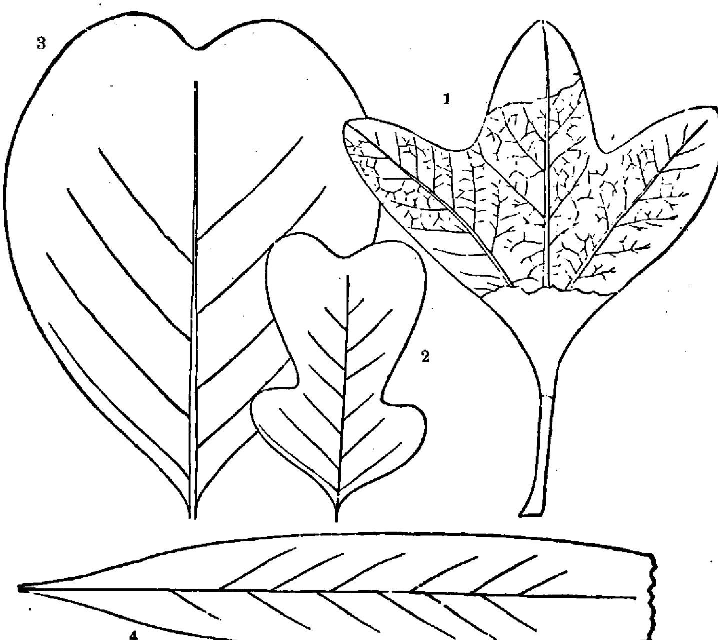


FIG. 344. Cretaceous plants. 1, *Leguminosites marcouanus;* 2, *Sassafras cretaceum;* 3, *Liriodendron meekii;* 4, *Salix meekii.* (After Dana.)

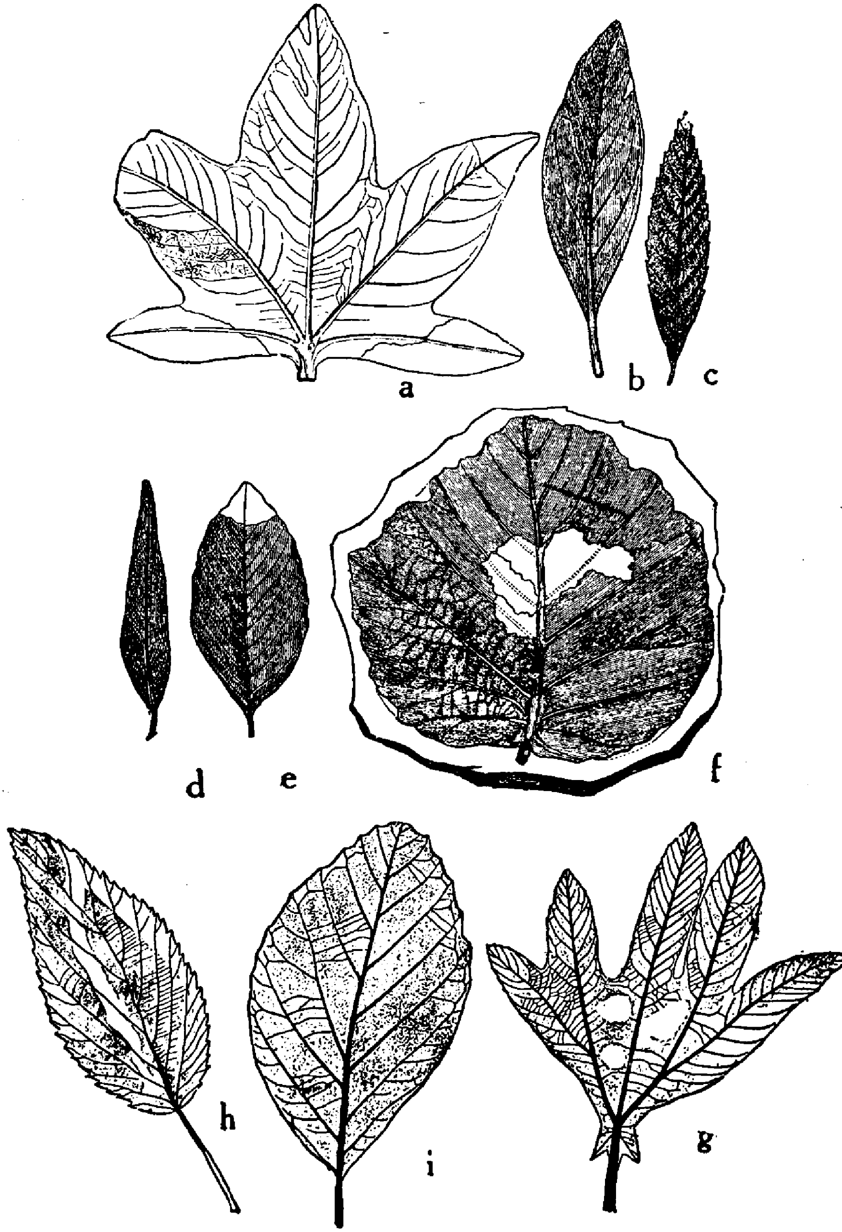


FIG. 345. TYPES OF PLANTS OF THE AMERICAN CRETACEOUS

a-f, Characteristic Middle Cretaceous plants, Dakota group: *a*, sweet gum (*Liquidambar integrifolium*); *b*, laural tree (*Laurus nebrascensis*); *c*, oak (*Quercus primordialis*); *d*, willow (*Salix proteæfolia*); *e*, beech (*Fagus polyclada*); *f*, *Protophyllum quadratum*; *g-i*, characteristic Upper Cretaceous plants (Laramie): *g*, sarsaparilla (*Aralia digitata*); *h*, arrowwood (*Viburnum newberrianum*); *i*, alder (*Alnus grewiopsis*). All reduced. (From Le Conte.)

FIG. 346. CRETACEOUS INVERTEBRATE FOSSILS

1, *Frondicularia major*, Bornemann, × 3, U. Cret., N. J. 2, *Haplophragmium concavum*, Bagg, × 12, U. C. 3, *Cardiaster cintus*, Morton, × ½, U. C. 4, *Terebratella plicata*, Say, × 1, U. C. 5, *Terebratula harlani*, Whitf., × ½, U. C. 6, *Inoceramus vanuxemi*, M. and H., × ½, Ft. Pierre. 7, *Aucella pioche*, Gabb, × 1, Knoxville. 8, *Idonearca nebrascensis*, Owen, × ½, Fox Hills. 9, *Exogyra costata*, Say, × ⅜, U. C. 10, *Veniella conradi*, Morton, × ⅝, U. C. 11, *Ostrea larva*, Lam., × ⅝, U. C. 12, *Pyropsis bairdi*, M. and H., × ½, Fox Hills. 13, *Anchura americana*, × 1, Evans and Shumard, Fox Hills. 14, *Baculites compressus*, Say, × ½, fragment of adult with suture lines, Ft. Pierre. 15, *The same*, a very young shell, × 5, showing apical coil. 16, *Scaphites nodosus*, Owen, × ⅜, Ft. Pierre. 17, *Heteroceras stevensoni*, Whitf., × 2/5, Ft. Pierre. 18, *Belemnitella americana*, Morton, × ½, U. C. (After W. B. Scott, "Introduction to Geology," permission of Macmillan Co.)

as Greenland, Alaska, the Mississippi Valley, and Argentina, we find the same or very similar plants, including even palms and figs. (Schuchert.) But many others of our common trees are represented, such as beech, oak, maple, magnolia, tulip tree, sassafras, elm, willow, and eucalyptus. And we have already seen that coal beds (composed largely of such plant materials) are found in the Upper Cretaceous beds on a very extensive scale, both in America (*Laramie* formation) and in Europe. And very obviously any theory regarding the origin of the coal beds must, to be adequate, take account of the kinds of trees in these Upper Cretaceous beds, as well as merely those in the Carboniferous.

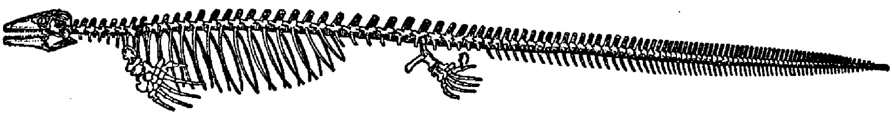


FIG. 347. A mosasaur (*Platecarpus coryphæus*) from the Upper Cretaceous of Kansas. About 1/36 natural size. (After Williston.)

Invertebrates. The lower forms of the invertebrates are not sufficiently different from those which we have already described to warrant specific mention here. But of the Mollusca, many kinds are distinctive, and will require further notice.

Oysters (Fig. 319) belonging to the genera *Ostrea, Gryphæa,* and *Exogyra,* are plentiful, many beds being packed with their remains; but the genus *Inoceramus* also is a good guide fossil. Even more characteristic are the remarkable shells called collectively *Rudistes,* which have one long horn-shaped valve, and have merely a cover for this to serve as the other valve. These strange pelecypods are divided into many genera; but they are regarded as confined exclusively to the Cretaceous, and are accordingly treated as horizon markers or "index fossils."

Fresh-water or brackish-water shells are quite common, and include many modern forms, such as the river mussel *Unio,* and the snails *Planorbis* and *Viviparus.* Other modern-looking shells, such as *Cypræa, Voluta, Fusus,* and *Murex,* are also common, and are much like the kinds found in the Tertiary beds.

But the *cephalopods* are most remarkable in their variety and in their astonishing forms. Many of the *Ammonites* have highly ornamented shells, with spines and nodes and flutings, some tightly coiled, some almost uncoiled, and some twisted into fantastic shapes. They are minutely subdivided, and are regarded as horizon markers.

Vertebrates. The *fishes* include many modern families and even many modern genera, such as the cod, salmon, herrings, mullets, and catfishes, with many that are now extinct, such as the *Portheus,* found in large numbers in the chalk beds of Kansas, which was sometimes 15 feet long, and had large reptile-like teeth.

The reptiles are much the same as we have already described from the Jurassic, though many of the largest forms are confined to the Cretaceous. A giant *plesiosaur,* called

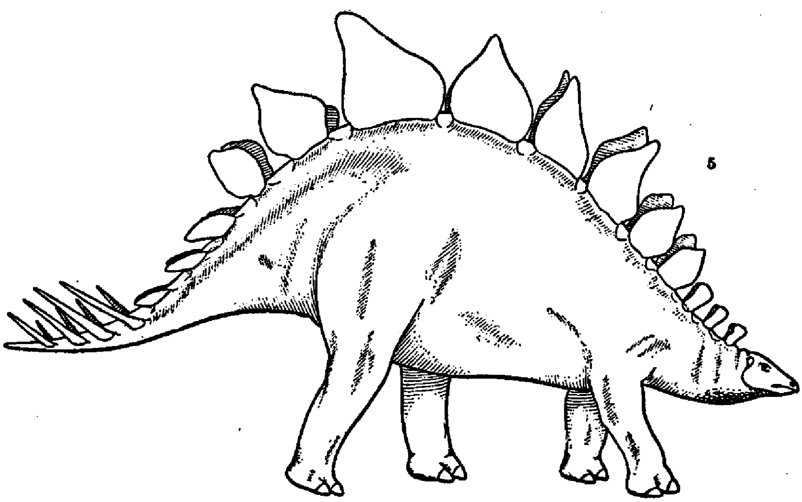
FIG. 348. Cross-bedding in Dakota sands (U. Cretaceous), south of Bennet, Nebraska. (Darton, U. S. G. S.)

Elasmosaurus, found in the Kansas chalk, was nearly 50 feet long, 22 feet of which was neck. The great *mosasaurs* (Fig. 347), with their comparatively slender bodies, must have been veritable sea serpents, one skeleton found in the Cretaceous of New Zealand being computed as being originally 100 feet long. From the frequent reports by competent observers of large serpentlike creatures which have been seen in the Gulf of Mexico and elsewhere, it is entirely possible that some of these creatures may have survived to our time.

The *dinosaurs* will be described more fully in a subsequent chapter. Most of the noted specimens seen in the various

museums of this country have come from the *Morrison, Laramie,* and *Denver* formations; while the European specimens have come chiefly from the *Wealden* of England, Belgium, and other parts of the Continent.

Two remarkable birds, *Hesperornis* and *Ichthyornis,* have been found in the Kansas chalk (*Niobrara* formation), which are somewhat like the famous *Archæopteryx* of Solenhofen, in that they had a good set of teeth. *Hesperornis* was about 6 feet high, with rudimentary wings; but the *Ichthyornis* was a smaller bird, with strong wings, and somewhat like a gull.



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CHAPTER XXXIV

Fossil Reptiles

Diversity. The characteristic animals of the Mesozoic formations are the reptiles; while the most interesting and the most remarkable of the reptiles are the *dinosaurs*. The latter constitute but one division of the Reptilia; but in point of diversity, the reptiles constitute almost a whole world of their own. In point of size, the reptiles found as fossils in the rocks range from the size

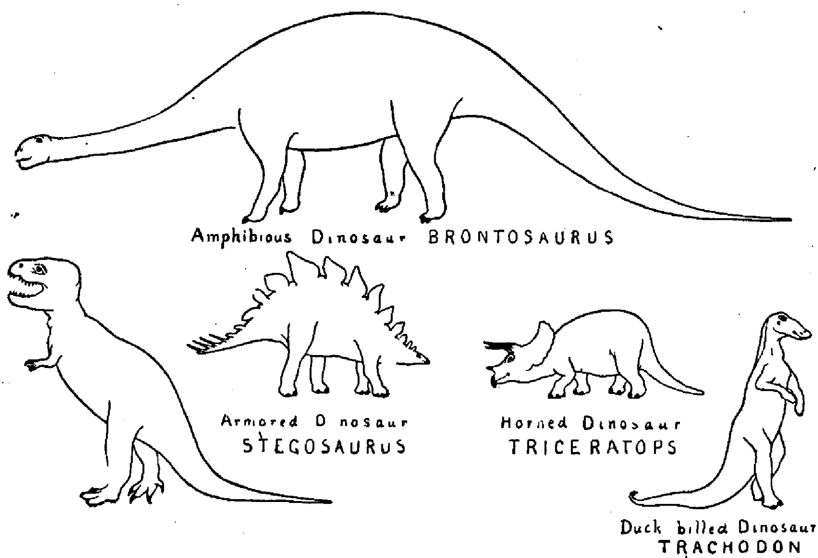

FIG. 349. Outline restorations of dinosaurs. Scale about nineteen feet to the inch. (From Matthew.)

of a small dog to monsters over 80 feet in length. Their habits of life were equally varied; for they embraced some which ate vegetables only, some which ate other animals only, and some which apparently ate anything at hand, either animal or vegetable. In still another view of the matter, we see an equal diversity; for some of them flew in the air, some swam in the ocean, others strutted around on the land on their hind feet alone, while still others walked on all fours. But whether in the air, in the water, or on the land, they are not only the chief forms of life in the rocks where they are found, but some of them far surpassed in size and strength any land animals now alive, and

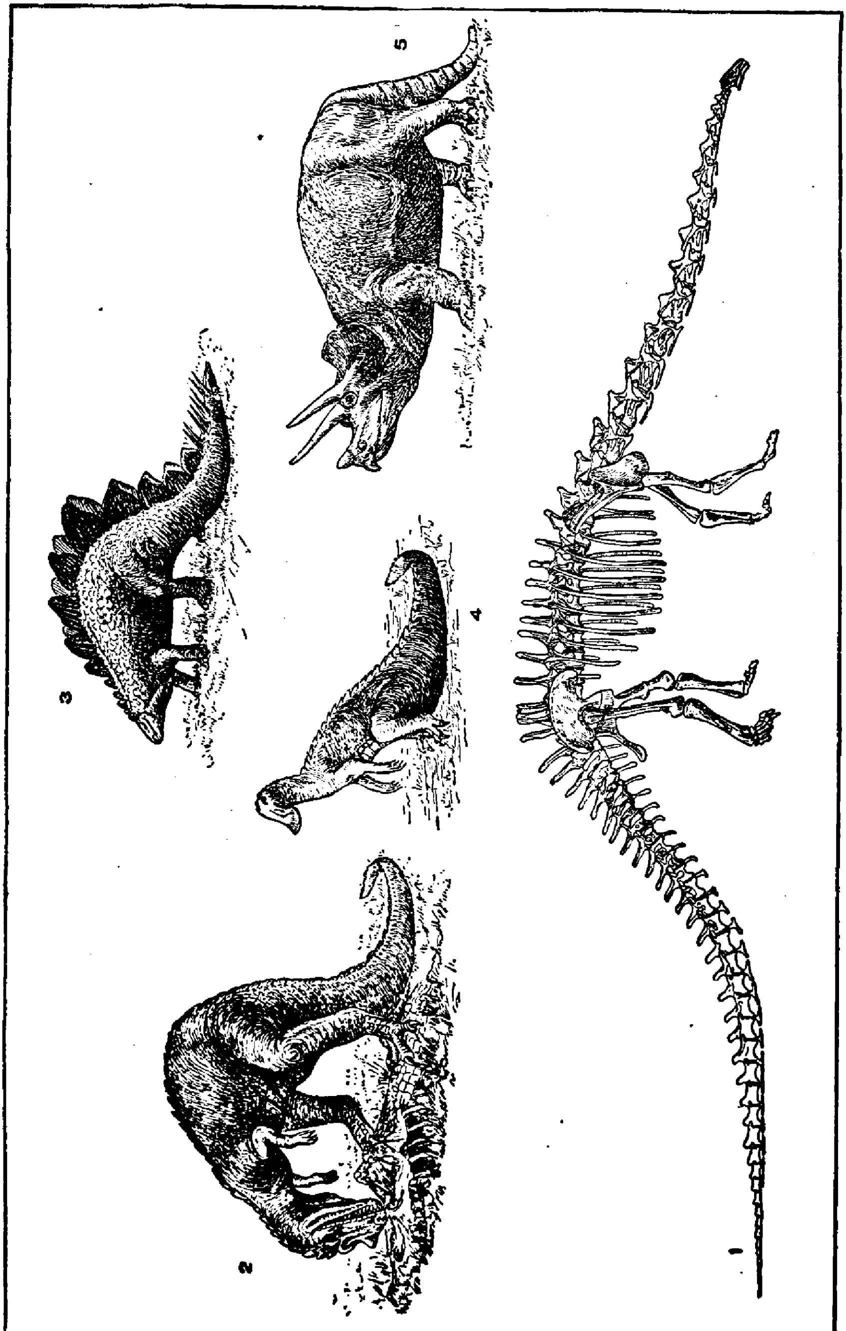

FIG. 350. DINOSAURS

Restorations of what scientists think some of these animals looked like. 1. Skeleton of Diplodocus (order Sauropoda); 2. Ceratosaurus (order Theropoda); 3. Stegosaurus (order Orthopoda); 4. Hadrosaurus (suborder Ornithopoda); 5. Triceratops (order Ceratopsia). (2-5, Restorations, after Osborn and Knight.) (From "The New International Encyclopædia," by permission.)

have been rivaled, either in ancient or in modern times, only by the whales.

Marine Reptiles. The *ichthyosaurs,* or *fish-reptiles,* were nearly 30 feet in length, and in outward appearance must have been much like a dolphin or a porpoise. They had a long, sharp snout, jaws armed with sharp teeth set in a continuous groove and not in separate sockets, a short fishlike neck, large, powerful flippers, and a very fishlike tail. The eye was large, and was protected by numerous bony plates, which are often preserved in the fossil state. These creatures were undoubtedly carnivorous and lived in the ocean; and certain beds of the Lower Jurassic (*Lias*) of England and Germany are literally packed with their skeletons, some of the specimens even showing the outlines of the body and of the limbs, and even the nature of the skin, which was smooth, with neither bony scutes nor horny plates. In Württemberg, Germany, there were in 1911 some 25 stone quarries in operation for the marketing of the slates there obtained; but in the course of this work, on an average about 100 specimens of fossil reptiles are found each year, of which about one in ten is sufficiently perfect to warrant preparation by experts. Lyme Regis, in Southern England, is another locality famous for similar remains of ichthyosaurs. The beds in which these fossils occur are usually strongly bituminous, or impregnated with oil; and many huge ammonite shells are found along with them, some of these shells being five or even six feet in diameter. The oil in these beds is best accounted for by the supposition that all these creatures were entombed alive, or at least before the flesh had decomposed.

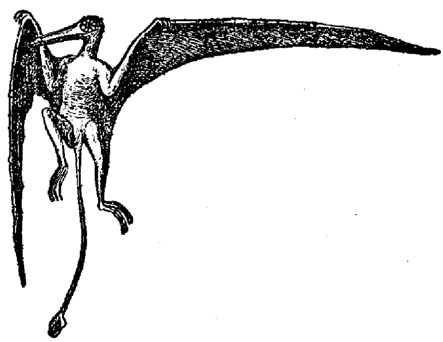

FIG. 351. Pterodactyl of the genus Rhamphorhynchus (restored). (From "The New International Encyclopædia," by permission.)

The *plesiosaurs* are another group of marine reptiles which make a marked contrast to the former group in appearance. They had a long, slender neck, with huge paddles nearly as long as the body, and a tail of proportionate length which tapered to a point. Some of these creatures were 20 or more feet long, while one genus, *Pliosaurus,* had paddles 6 feet in length. Another, named *Elasmosaurus,* found in the Cretaceous rocks of Kansas, was nearly 50 feet long, "of which 22 feet was neck."

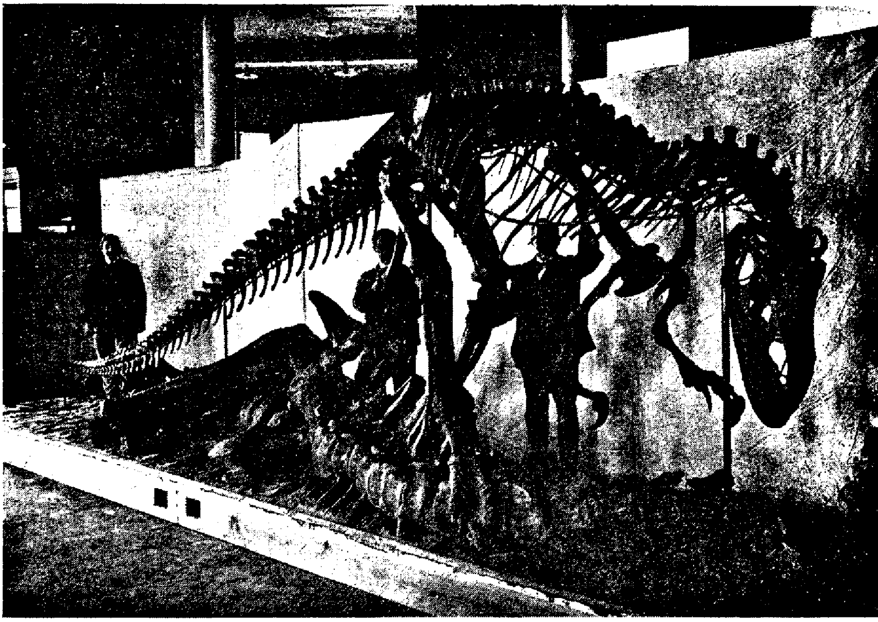

FIG. 352. Allosaurus skeleton mounted. (American Museum of Natural History, New York City.)

(Schuchert.) A related tribe, having scales and movable lower jaws, as in snakes, were even more snakelike in appearance, and constituted veritable "sea serpents." They have been named *mosasaurs,* and are found in great numbers in the Kansas Chalk, and also in the south of England and the Netherlands. One of the largest specimens, found in New Zealand, seems to have been about 100 feet long (Gadow); but only imperfect fragments have been found.

Flying Reptiles. The flying reptiles are called *pterosaurs,* though one genus of the group, *Pterodactylus,* is better known than the others. The pterosaurs had real wings, quite like those of a bat; and as they could doubtless fly with the greatest ease, they would serve to justify the tradition of flying dragons. The head was large, with a capacious brain cavity, and was set at right angles to the neck, as in birds. Some of these flying reptiles had a full set of teeth, and are thought to have been carnivorous. Some may have been frugivorous. The joints of what would correspond to the little finger of the hand were greatly enlarged and enormously lengthened out, until in total length this "finger" was longer than the body and the legs together. To this "finger," a membrane, or *patagium,* was attached, which

extended from this long framework of a finger down to the flanks of the body and the hind limb, thus forming a true wing, very much like that of a bat, but quite unlike that of a bird. Some specimens of these animals found in the limestones of Solenhofen, Germany, show distinctly the impressions of these wing membranes, the animals evidently having been buried before decomposition took place. The bones were like those of birds in being hollow, or *pneumatic;* and there was a true *keel* or breastbone, as in birds, for the attachment of the strong muscles used in flying — a structure which is found also in both birds and bats. Some of these pterosaurs were small, with a spread of wing of only two or three feet; while others had a head a yard long, and a stretch of wing of over 20 feet.

Plenty of true crocodiles, lizards, and turtles are found as fossils, with some few snakes. One of the marine turtles found in the Cretaceous strata was nearly 11 feet long, and 12 feet across the front flippers. But without dwelling on the details of these, we may pass on to notice in more detail the characteristics of the *dinosaurs,* some of which were the mightiest monsters that ever marched across dry land.

Dinosaurs. The *dinosaurs* are usually divided into two main groups, the herbivorous and the carnivorous, these groups being based on the best we can decide regarding the diet of these

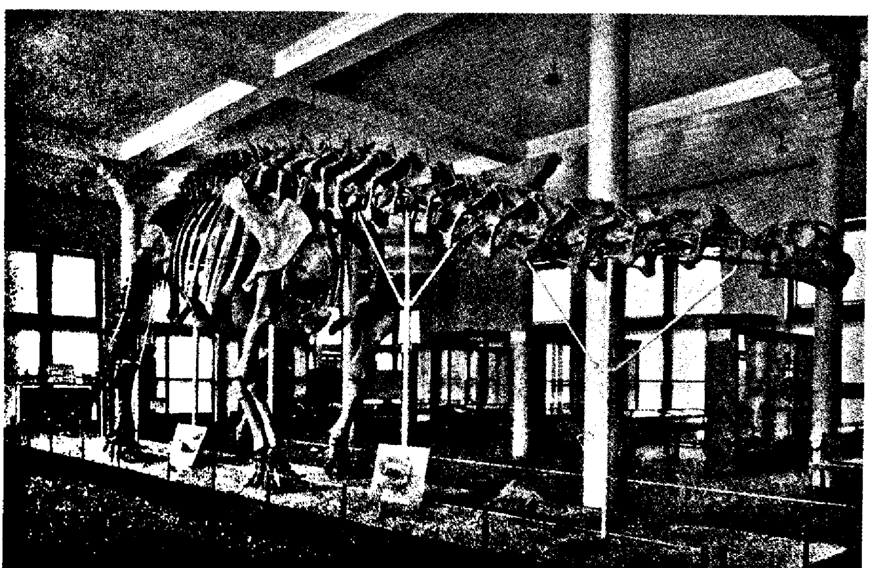

FIG. 353. Mounted skeleton of Brontosaurus in the American Museum, New York.

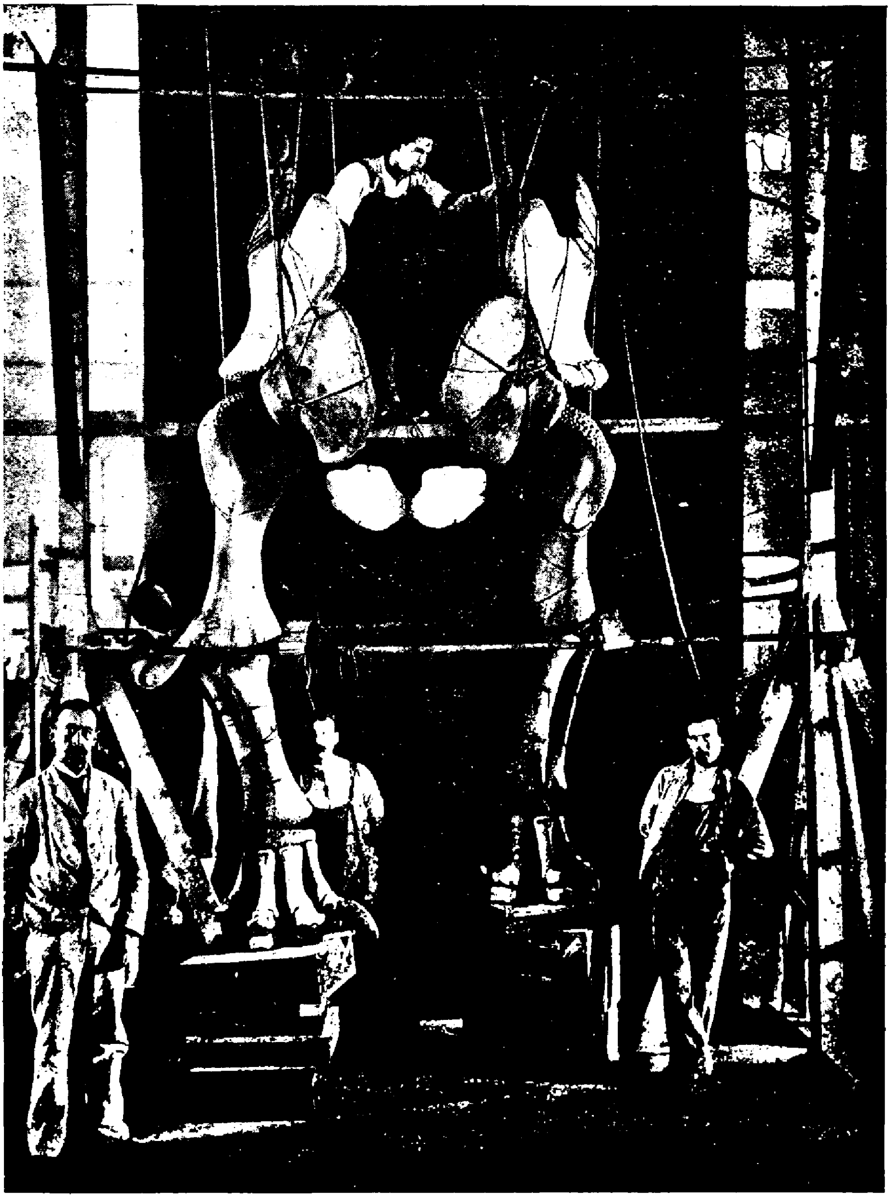

FIG. 354. Mounting the skeleton of a *Brontosaurus*. (American Museum of Natural History, New York City.)

animals from their teeth, their feet, and a few other structures.

One race of herbivorous dinosaurs had a turtlelike beak in the front of the mouth, and a wonderful battery of several rows of teeth farther back on the jaws.

Another group are called the *bird-footed* dinosaurs. Some of these were small, only about 5 feet in length, while others were at least 40 feet long. One of the striking features of this and other groups, especially of the carnivorous dinosaurs, was the very short, almost useless fore limbs, which in some of the species were even shorter in proportion than the fore limbs of the kangaroo. Like the kangaroos, these animals had long and strong hind legs, and a powerful tail, the latter acting like a rudder or a third leg. If they were as correspondingly quick in their movements as some of the modern lizards, they must have been speed breakers.

A description of one of these bird-footed dinosaurs will serve as more or less applicable to the group:

"A fortunate discovery made in Niobrara County, Wyoming, in 1908, brought to light a specimen of *Trachodon* which, because of the marvelous preservation, permits an almost perfect mental reconstruction of the animal. The dinosaur had apparently died where it could be gradually desiccated under the heat of a tropical sun until the skin and much of the flesh and tendons had shrunken down upon the bones. In places the skin is thrown into the finest wrinklings, showing it to have been as thin as that of a python; but in contrast to that of the snake, it bore not scales but tubercles, some rather large, others excessively fine, but showing a distinctive arrangement. There is, however, over the entire body no trace of defensive armor. The curious webbed character of the hand, and the presence, in other specimens, of a powerful compressed tail, point to an animal with the swimming powers of an alligator, but still retaining the ability to travel rapidly on land. Hence *Trachodon* was able to avoid the onslaught of the omnipresent carnivore, not alone by its speed ashore, but by taking to the water when hard pressed."—*Lull.*

These trachodonts had a huge ducklike bill, and are accordingly called the *beaked* dinosaurs. They have been found quite plentifully in Montana and the Dakotas, as well as in Wyoming; also in New Jersey, Mississippi, and Alabama. Not all the specimens have been so excellently preserved, though some seven specimens have been found which are practically "mummies."

The *Stegosauria* were *armored* dinosaurs, covered with a coat of mail like that of the modern crocodiles, the hide of which will turn a rifle bullet. Some of the stegosaurs, however, had a much more complete armor than any crocodile or alligator, and resembled nothing so much as a living castle or battle "tank"; and it must have been almost impossible for an enemy to capture or subdue them. Lull calls them "animated citadels." *Stegosaurus* had a double row of large plates up and down its back, the ones over the pelvic region being 2 feet high, 2½ feet long, and 4 inches thick at the base, thinning out at the edges. On its tail were 4 or more huge spines, these spines being 2

feet long and 5 or 6 inches thick at the base, making the tail a veritable mace or battle club.

Size of Brain. These creatures had a ridiculously small brain, estimated at only 2.5 ounces, while the body was equal in weight to that of an elephant, and the latter has a brain at least 20 times as great. However, *Stegosaurus* had in addition, in the sacral portion of the spinal column, a very large cavity, some twenty times the size of the real brain. This second "brain" doubtless controlled all of the instinctive and reflex actions of the animal; and if its diminutive brain in the skull indicates that the animal must have been excessively stupid, its sacral "brain" must have been sufficient to keep its body functioning in good shape, and it had such an elaborate set of defensive armor that it probably was not much annoyed by attacking enemies.

Many of these ancient reptiles had less than half a pound of real brain for each ton of body weight, and they weighed from 10 to 38 tons or even more. Man has about 2 pounds of brain to every 100 pounds of body weight, or 80 times as much proportionately.

In this connection, one can hardly refrain from quoting what a certain wag has written about the brains of these strange creatures:

"Behold the mighty dinosaur,
Famous in prehistoric lore,
Not only for his weight and strength,
But for his intellectual length.
You will perceive by these remains
The creature had two sets of brains —
One in his head (the usual place),
The other at his spinal base.
Thus he could reason *a priori*
As well as *a posteriori*.
No problem bothered him a bit;
He made both head and tail of it.
So wise was he, so wise and solemn,
Each thought filled just a spinal column.
If one brain found the pressure strong,
It passed a few ideas along;
If something slipped his forward mind,
'Twas rescued by the one behind;
And if in error he was caught,
He had a saving afterthought.
As he thought twice before he spoke,
He had no judgments to revoke;.
For he could think, without congestion,
Upon both sides of every question."

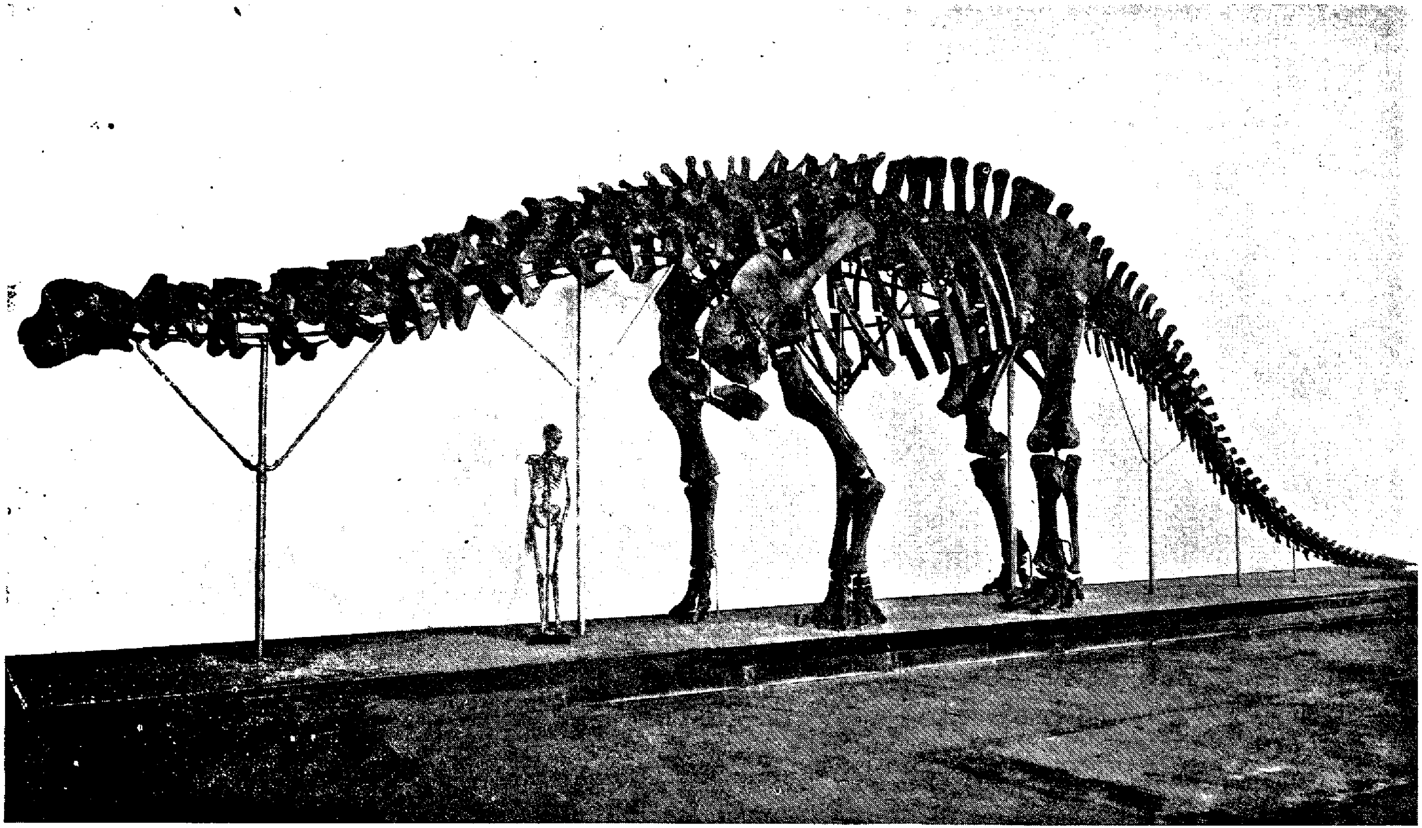

FIG. 355. *Brontosaurus excelsus.* (American Museum of Natural History, New York.)

Other Characters. Another group of plant-feeding dinosaurs possessed a huge head armed with horns, two, or three, or even five in number, set on various parts of the face and head, the bases of which were correspondingly strengthened with a solid bony structure to carry these massive projections. Some of these creatures had in addition a strong bony crest projecting backward from the back of the head over the neck and shoulders, like a massive flange or bony shield, which must have been of material protection to its owner when charging an enemy. Many of the specimens recovered as fossils show a great assortment of wounds which had been received by these animals during their lives; for horns and jaws have been broken and healed, skulls have been found pieced and grown together, and in all these ways we have an indication of the kind of life which these old battle-scarred veterans lived. And as the creatures continued to *grow as long as they lived,* their monstrous size is a pretty good index of their age, which was doubtless measured by centuries.

"Unlike man and the higher vertebrates, reptiles and fishes do not have a maximum size which is soon reached and rarely exceeded, but continue to grow throughout life, so that the size of a turtle, a crocodile, or a dinosaur tells something of the duration of its life. If tortoises may attain an age of several hundred years, why should not a dinosaur grow to be much older?" — *Schuchert.*

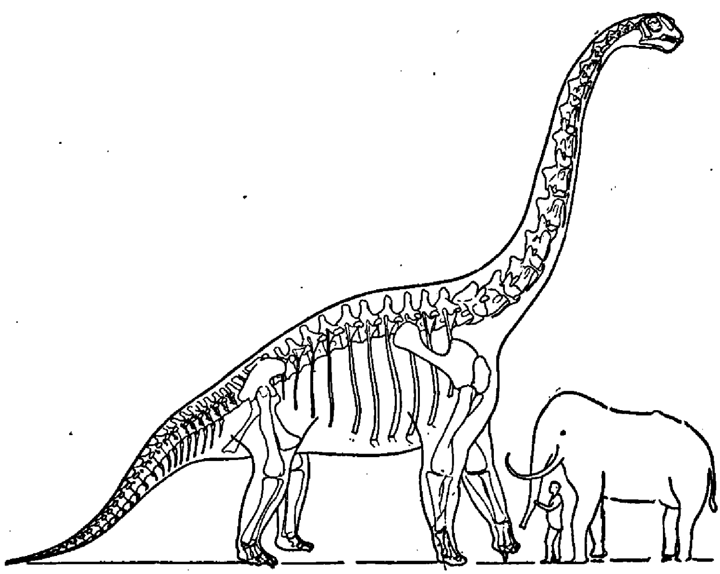

FIG. 356. The largest known dinosaur. Sketch reconstruction of *Brachiosaurus,* from specimens in the Field Museum in Chicago, and the Natural History Museum in Berlin. (After W. D. Matthew.)

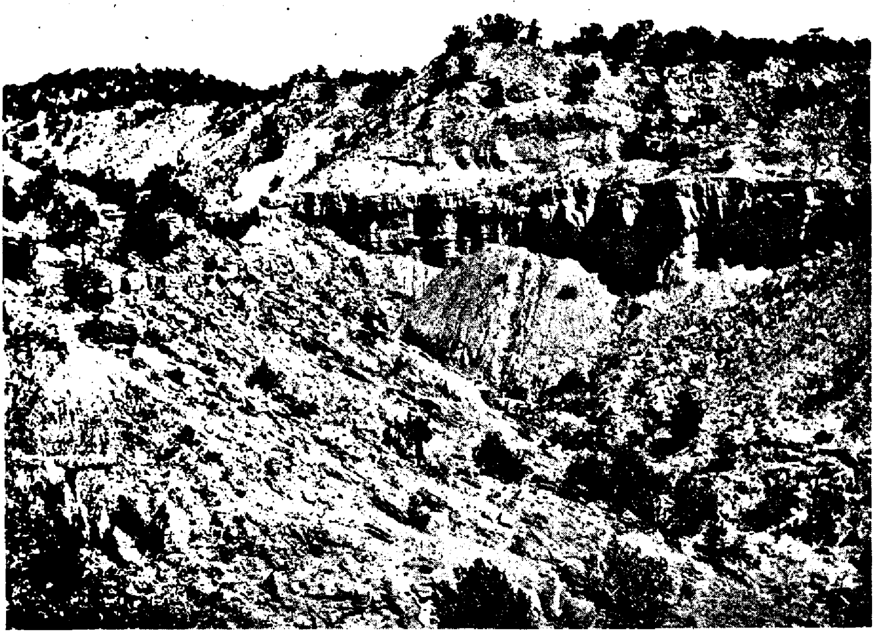

FIG. 857. View of the "Marsh quarry" for vertebrate fossils, in the Morrison formation, Garden Park, 9 miles north of Cañon City, Colorado. This shows the irregular character of the sandstone underlying the dinosaur bed. (Stanton, U. S. G. S.)

Size. Several specimens have been found in the Cretaceous beds of the West, of the massive *Tyrannosaurus,* or "tyrant saurian," as it has been named. This animal was some 47 feet long, and must have had a body as large as the very largest of the elephants. At it walked chiefly on its hind legs and its powerful tail, it was probably from 18 to 20 feet high, whereas the largest of living elephants are only about 12 feet high. *Tyrannosaurus* had immense sharp claws on its hind feet, even those on its small front feet being 6 to 8 inches in length, and curved like those of a bird of prey. The head of one specimen in the American Museum of Natural History, New York City, is 4 feet 3 inches long, 3 feet 4 inches deep, and 2 feet 9 inches wide, the massive jaws being set with teeth from 3 to 6 inches long and an inch wide. As this animal was undoubtedly carnivorous, it certainly was a tyrant monster. Scientists have thought that it must have been slow and sluggish in its movements; but of this we can not be certain.

But mightiest of all the monsters that ever walked the earth were the huge *Sauropoda,* or reptile-footed beasts, such as *Dip-*

lodocus, and *Brontosaurus*, examples of which are to be seen in several of our chief museums.

Dr. W. D. Matthew tells us that many of the visitors of the Natural History Museum, on entering the Dinosaur Hall, remark in a casual way, "They make these out of plaster of Paris, don't they?" This incredulity on the part of these people reminds Dr. Matthew of the old farmer's indignant retort on seeing a giraffe for the first time—"There ain't no sich animal." Were it not for the incontestable proofs of the very bones themselves, one could scarcely believe that such outlandish-looking monsters ever lived on earth.

FIG. 358. *Triceratops* horn *in situ*, showing below Dr. T. W. Stanton, of the United States Geological Survey. Oregon Basin Quadrangle, Wyoming. (Hewitt, U. S. G. S.)

The skeleton of *Brontosaurus* (*thunder-lizard*) in the American Museum of New York is 66 feet 8 inches long, and the live animal must have weighed about 38 tons. It had a very long, tapering neck and tail, "as though an elephant were deprived of its normal terminals and provided with those of an enormous snake." (Lull.) The specimen of *Diplodocus* in the Carnegie Museum in Pittsburgh is 87 feet long, though a little slenderer than *Brontosaurus*.

Food. As there must have been large numbers of these animals, it is difficult to imagine what they could have found to live on. The teeth of *Brontosaurus* are spoon-shaped, and confined to the front part of the jaws, so that it is hard to see what good they could have been in chewing. It has been conjectured that the creature lived on the abundant plant life of marshes and river bottoms, and that it swallowed its food with little or no mastication. The finding of smoothly polished stones within the ribs of some specimens has suggested that the animal may have had a gizzard, which may have acted as a digestive mill to grind up the food it had swallowed in haste; for the amount it required daily has been estimated at about half a ton of plants. It is supposed to have been amphibious, somewhat like the crocodile or the hippopotamus.

Skeleton. "The skeleton of one of these creatures is a marvel of mechanical design; the bones of the vertebral column are of the lightest possible construction consistent with strength, the bony material being laid down only where stresses arise, and reduced to a minimum at other points. The assembled skeleton reminds one forcibly of a cantilever bridge borne on two massive piers — the limbs — between which the trunk represents the shorter channel span, and the long neck and tail the spans leading to the shores. Over the hips is a ridged anchorage formed by the coalescence of several vertebræ, for not only was this the point of origin of the tendons and sinews supporting the 30 feet of tail, but on occasion the whole forward part of the body, fore limbs, and neck could be raised clear of the ground after the manner of a bascule bridge. In the refinement of its architecture the vertebral column is essentially Gothic, with arch, pillar, and buttress, and the freedom of design characteristic of the great fabrics of medieval time."— *Lull.*

A closely related saurian, named *Brachiosaurus,* has been found in German East Africa. It was apparently about 80 feet long, while its neck alone is given as 36 feet, and each of its cervical vertebræ was from 3 to 4 feet long. Its tail was relatively short; its fore legs were longer than the hind ones, and the upper bone (humerus) of the front leg measured 6.5 feet. This animal was probably larger than the *Brontosaurus.*

Where Found. Skeletons of fossil reptiles have been found in great numbers in numerous localities among the foothills of the Rocky Mountains, from Wyoming to New Mexico and Texas, with outlying patches of similar beds in the Black Hills and in Western Colorado. Many of these scattered beds, called collectively the *Morrison* formation, have been variously classed as Jurassic or Cretaceous; and the dispute about their exact "age" is still going on. Others are classed as "Upper Cretaceous"; but it is sufficient to know that these fossils are in many cases found in

FIG. 359. Irregular bedding in sands and carbonaceous shales of "Ceratops beds" (Cretaceous), where bones of dinosaurs are found, on the east bank of the Little Missouri, Marmarth, North Dakota. Lignite beds below. (Stanton, U. S. G. S.)

the surface strata, and that these strata are often not more consolidated than the very similarly situated and very similar-appearing Tertiary beds of other localities.

"In the arid Western regions these formations girdle the Rockies and outlying mountain chains for two thousand miles from north to south, and are extensively exposed in great escarpments, river cañons, and 'bad-land' areas, bare of soil and vegetation and affording an immense stretch of exposed rock for the explorer."— *Matthew.*

The flora found associated with these fossil animals is much like that of the warmer parts of our modern world, though confessedly the *combinations* of trees and plants are different from the present assemblage in any one locality. Besides many common temperate-climate trees, this flora includes palms, like the palmetto of Florida, the gingko of China and Eastern Asia, the fig, and the Sequoia, like the big redwoods of California. But the plants are very markedly *modern* in aspect; and there is not the slightest warrant for saying that the associated reptilian remains collectively are a day older than the Tertiary beds of the Western States and of Europe. Nothing but pure, unfounded hypothesis and theoretical speculation

stands in the way of our saying that these reptiles were contemporary with the almost equally gigantic mammals whose skeletons are found in other parts of these Rocky Mountain regions, as well as in various parts of the Old World.

Their Extinction. This being so, the problem of *how these animals became extinct* assumes a very important place in the general geological problem of how these ancient animals were destroyed and buried where we now find their remains. And the problem is not at all narrowed down to Europe and America. As we have seen, one of the largest of these brutes has been found in German East Africa; other dinosaurs have also been found in Madagascar, in India, and in Patagonia, South America; and we must remember that the geological study of the vast regions in the tropics has only fairly begun. But if these gigantic reptiles can not be separated, in the problem of their extinction, from the huge prehistoric mammals, such as the megatherium, the titanotheres, the mastodon, and the other ancient elephants, we have indeed a large problem on our hands urgently needing an explanation.

"One of the most inexplicable of events," says Professor Lull, referring to the dinosaurs, "is the dramatic extinction of this mighty race." But if to this problem we have added also the extinction of the great numbers of elephants, rhinoceroses, camels, mastodons, megatheriums, and what not, over all of North America (to say nothing of the other continents), we shall have to make allowance for such phenomena when attempting to frame a true and adequate induction regarding the way in which the geological changes of the past really took

Fig. 360. Laramie beds (U. Cretaceous) on the west side of the Missouri River, 6 miles north of Cannon Ball, North Dakota. Dinosaur bones occur in the lower part. (Stanton, U. S. G. S.)

place. "The cutting off of this giant dinosaur dynasty was nearly if not quite *simultaneous the world over,*" says Dr. W. D. Matthew. But what if all these other animals are also to be included in this event? Can any system of uniformitarianism be framed which will bear such a strain as the attempt to account for *all this at once?*

Hunting Fossils. We must present a few quotations to illustrate how the bones of these animals occur in the great regions of the West, as well as to show how explorers have had to work to secure specimens of these animals for our great museums.

Henry Fairfield Osborn thus describes the first exploration of the famous "Bone-Cabin quarry," not far from the Medicine Bow River, in Central Wyoming:

"In the spring of 1898, as I approached the hillock on which the ruin stands, I observed, among the beautiful flowers, the blooming cacti, and the dwarf bushes of the desert, what were apparently numbers of dark brown bowlders. On closer examination, it proved that there is really not a single rock, hardly even a pebble, on this hillock; all these apparent bowlders are ponderous fossils which have slowly accumulated or washed out on the surface from a great dinosaur bed beneath. A Mexican sheep herder had collected some of these petrified bones for the foundations of his cabin, the first ever built of such strange materials. The excavation of a promising outcrop was almost immediately rewarded by finding a thigh bone nearly six feet in length which sloped downward into the earth, running into the lower leg and finally into the foot, with all the respective parts lying in the natural position as in life. This proved to be the previously unknown hind limb of the great dinosaur, *Diplodocus.*"— *"Century Magazine," 1904, Vol. 68, pp. 680-694.*

Some ten miles south of this locality, across the Laramie plains, is the *Como Bluffs* quarry, believed to be in the same set of beds, which are thought to have once been continuous over all the intervening region. These dinosaur beds are some 274 feet in total thickness; but remains of marine saurians are found in beds supposed to be both above and below these, ichthyosaurs in the beds below, and mosasaurs in the beds alleged to be above them.

At the Como Bluffs, says Professor Osborn, "single animals lie from twenty to one hundred feet apart; one rarely finds a whole skeleton, such as that of Marsh's *Brontosaurus excelsus,* the finest specimen ever secured here, which is now one of the treasures of the Yale museum. More frequently a half or a third of a skeleton lies together.

"In the Bone-Cabin quarry, on the other hand, we came across a veritable Noah's-ark deposit, a perfect museum of all the animals of the period. Here are the largest of the giant dinosaurs closely mingled with the remains of smaller but powerful carnivorous dinosaurs which preyed upon them, also

those of the slow and heavy-moving armored dinosaurs of the period, as well as of the lightest and most birdlike of the dinosaurs. Finely rounded, complete limbs from eight to ten feet in length are found, especially those of the carnivorous dinosaurs, perfect even to the sharply pointed and recurved tips of their toes. Other limbs and bones are so crushed and distorted by pressure that it is not worth while removing them. Sixteen series of vertebræ were found strung together; among these were eight long strings of tail bones. The occurrence of these tails is less surprising when we come to study the important and varied functions of the tail in these animals, and the consequent connection of the tail bones by means of stout tendons and ligaments which held them together for a long period after death. Skulls are fragile and rare in the quarry, because in every one of these big skeletons there were no fewer than ninety distinct bones which exceeded the head in size, the excess in most cases being enormous."— *Ib.*, *id.*

In the year 1878, soon after the first discovery of these dinosaur bone beds, the following was written by one who was intimately connected with their first exploration:

The failure of the earlier explorers to find these marvelous bone beds, we are told, "is all the more remarkable from the fact that in several of the localities I have observed acres literally strewn with fragments of bones, many of them extremely characteristic and so large as to have taxed the strength of a strong man to lift them. Three of the localities known to me are in the immediate vicinity, if not upon the actual town sites, of thriving villages, and for years numerous fragments have been collected by (or for) tourists and exhibited as fossil wood. The quantities hitherto obtained, though apparently so vast, are wholly unimportant in comparison with those awaiting the researches of geologists throughout the Rocky Mountain region. I doubt not that many hundreds of tons will eventually be exhumed." (Williston.) Later this author says that his prediction of many hundreds of tons being unearthed in these regions, has been well fulfilled; though "how many tons of these fossils have since been dug up from these deposits in the Rocky Mountains is beyond computation." They are found in all the leading museums throughout the world.

Recovering Fossil Vertebrates. The following is a good description of how the work of actually getting these bones out of the rock is accomplished:

"The heavy ledges above are removed with pick and shovel, often with the help of dynamite and a team and scraper. As he gets nearer to the stratum in which the bones lie, the work must be more and more careful. A false blow with pick or chisel might destroy irreparably some important bony structure. Bit by bit he traces out the position and lay of the bones, working now mostly with awl and whisk broom, uncovering the more massive portions, blocking out the delicate bones in the rock, soaking the exposed surfaces repeatedly

with thin 'gum' (mucilage) or shellac, channeling around and between the bones until they stand out on little pedestals above the quarry floor. Then, after the gum or shellac has dried thoroughly and hardened the soft parts, and the surfaces of bone exposed are further protected by pasting on a layer of tissue paper, it is ready for the 'plaster jacket.' This consists of strips of burlap dipped in plaster of Paris and pasted over the surface of each block until top and sides, all but the pedestal on which it rests, are completely cased in, the strips being pressed and kneaded close to the surface of the block as they are laid on. When this jacket sets and dries the block is rigid and stiff enough to lift and turn over; the remains of the pedestal are trimmed off and the under surface is plastered like the rest. With large blocks it is often necessary to paste into the jacket, on upper or both sides, boards, scantling or sticks of wood to secure additional rigidity. For should the block 'rack,' or become shattered inside, even though no fragments were lost, the specimen would be more or less completely ruined.

"The next stage will be packing in boxes with straw, hay, or other materials, hauling to the railway, and shipment to New York."—*Matthew, "Dinosaurs," pp. 118, 119.*

CHAPTER XXXV

The Cenozoic Group—The Tertiary System

Classification. In the Cenozoic, we have the last of the great geological divisions. By those who believe in the geological ages, it is called the Age of Mammals and of Modern Floras. The following are the subdivisions as given by Schuchert and others:

CENOZOIC	Quaternary	Drift or "Glacial"	Pleistocene
	Tertiary	Late Tertiary (Neogene)	Pliocene Miocene
		Early Tertiary (Paleogene)	Oligocene Eocene Paleocene

Historical. In the early days of geology, the entire series of rocks was divided into *Primary, Secondary, Tertiary,* and *Quaternary.* Thus these last two names are a survival of an old system of classification, and are continued to-day in geological nomenclature merely as a matter of convenience, though they have entirely lost their etymological significance. In the days of Werner, what we now call the Tertiary was termed the *Alluvium,* and was supposed to represent the work done by the great Deluge of Noah. About 1810, however, Cuvier and others began to study carefully the strata underlying Paris, made up of sands, clays, marls, limestone, gypsum, etc., lying quite horizontally and mostly unconsolidated. A little later the strata under and around London and in Hampshire, in the south of England, were studied, and were thought to be the exact equivalents of those in the so-called *Paris basin,* those in England being termed the *London basin* and the *Hampshire basin* respectively. These English beds were regarded as the equivalents of those in France, because in each case, these beds rested upon the Chalk beds. Presently similar deposits were described as being very abundant on the flanks of the Apennines, in Italy; and a little later others were found in the south of France which were supposed to be *intermediate between* those of the Paris basin and those of Italy. In 1833, Sir Charles Lyell worked out

a table showing the percentage of "living" and "extinct" Mollusca in these different beds; and on this basis, he arranged them in chronological order as follows, reading upward:

Pliocene	Sub-Apennines	35 to 50% living species
Miocene	South of France	17% living species
Eocene	London and Paris	3½% living species

With further study, these percentages were found to be somewhat inexact; but the method has been adapted to the progress of discovery, and in its revised form is still largely used as the basis for classifying these Tertiary and Post-Tertiary or Pleistocene deposits. The following is the present system of classification, as given by Schuchert:

Quaternary		Pleistocene	from 90 to 100% of living Mollusca
Tertiary	Neogene	Pliocene	from 50 to 90% of living Mollusca
		Miocene	from 20 to 40% of living Mollusca
	Paleogene	Oligocene	from 10 to 15% of living Mollusca
		Eocene	from 1 to 5% of living Mollusca
		Paleocene	practically no living Mollusca

The Artificiality of These Subdivisions. As will be very readily understood, these subdivisions of the Tertiary system (and also of the Quaternary) are the most arbitrary and artificial of all the geological classifications. The beds are more frequently in isolated patches here and there, giving less opportunity for stratigraphical comparisons, and this fact has given more opportunity for the full exercise of this percentage system of classification. Of course, to-day it is not the Mollusca alone which are thus considered in deciding whether a certain set of beds should be classed as Eocene, Miocene, or Pliocene; all the other types of life are also taken into consideration. For instance, it is assumed that all the mammals of the Tertiary are *extinct* species. In actual practice, this means that whenever fossil mammals are found which are plainly like living species, they must be excluded from the Tertiary, and called Post-Tertiary or Pleistocene; or, as another alternative, a *new generic name* can be invented for them, and then they can be left in the Tertiary and regarded as "extinct species." On the other hand, if in a new set of beds the fossils do not show any close approximation to modern living forms — if, for example, they should happen to contain bones of large reptiles — the beds would then have to be assigned to the Mesozoic. If, however, they contained mammals, but of a very strange or "primitive" type, the beds might be classed as Paleocene or Eocene, certainly not as Pliocene or Pleistocene.

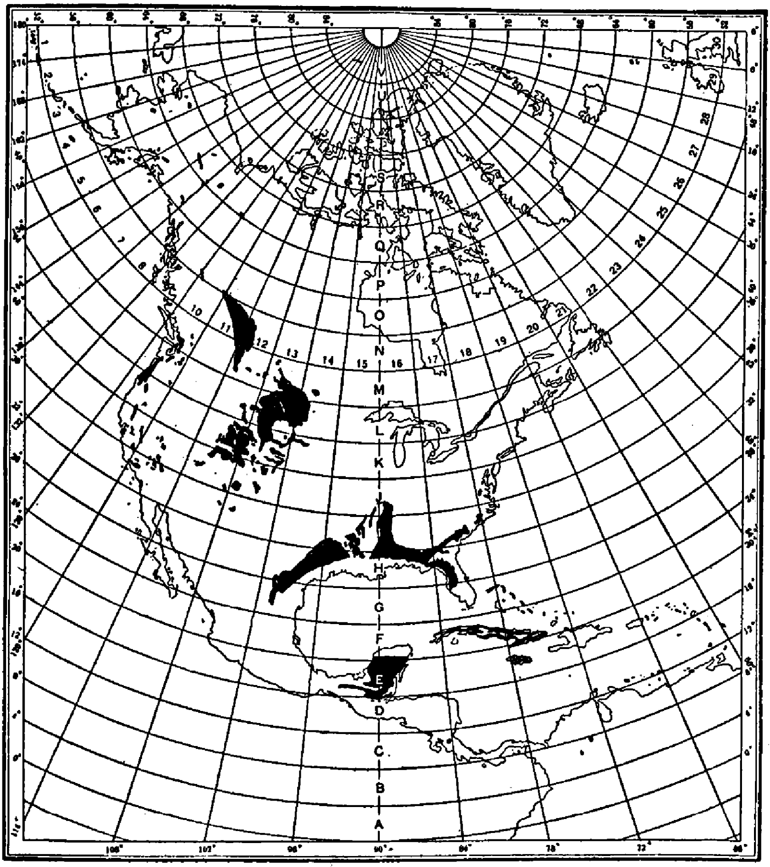

FIG. 361. Map showing the outcrops of the "earlier" Tertiary rocks (Eocene and Oligocene) in North America. (After Bailey Willis, U. S. G. S.)

Under these circumstances, the various divisions of the Cenozoic group could hardly fail to show a *graded approximation* to the modern living types of life. But to claim that the results of such an artificial arrangement prove anything regarding the way in which the various lines of animals have evolved, such as the horse, the elephant, the camel, or the hog, is to show a lack of mental clearness.

Difficulties. In actual field work, it is often impossible to say to which of these subdivisions a certain set of strata should be assigned. This difficulty is evaded or postponed by the very sensible custom of giving to these beds a local geographical name, and awaiting the pronouncement of expert paleontologists for the exact classification. This is a very convenient method

in itself; but it also serves to illustrate the purely artificial character of this whole system of classification.

Usually it has not been very difficult to find a way of placing a new set of beds wholly in the Tertiary, or wholly in the Mesozoic; and thus it has long been the custom to speak of the marked break in the fossils in passing from the Cretaceous, the last division of the Mesozoic, to the first of the Tertiary. But in many areas, as in the Great Plains region east of the Rockies, formations have been found where the animals, both vertebrates and invertebrates, should be classed as Cretaceous, while the plants are those of the Tertiary (*Fort Union* formation).

Consolidation. Many beds of the Tertiary formations are composed of unconsolidated materials. This was the case in England and France, where these strata were first examined; and it was long assumed to be the case with the Tertiary formations everywhere. But with the progress of exploration, many instances have been found where beds which must be classed as Tertiary are just as fully consolidated and metamorphosed as any of the so-called "older" formations. Eocene schists in the Alps and Eocene marbles in the Himalayas are examples of this sort; while in many places on the Pacific coast, even the middle or "later" Tertiaries "are folded or otherwise altered so that they are as much consolidated as are the formations of the Paleozoic." (Schuchert.) As we shall see in a later chapter, this is also true even of some of the strata classed as Pleistocene or Post-Tertiary.

Paleocene Series

Distribution. In America, so few localities are known where rocks are found which can be classed as *Paleocene,* that this name is not in common use in this country, the Eocene being made to include all the first formations of the Tertiary. In Europe, this term has been used for some time, and it is receiving wider recognition of late in this country as well.

To the east of the Rockies are large areas (the *Denver* and the *Livingstone beds*) which by some are classed with the Paleocene, because of the fossil plants which they contain. But as they contain also remains of dinosaurs, most geologists place them with the Cretaceous. The *Fort Union beds,* however, which are extensively shown in Wyoming, Montana, North Dakota, and Canada, are quite generally classed as the lowest of the real Tertiary beds. They consist chiefly of clays and sandstones, and contain the remains of some fresh-water shells; but the fact that they contain also the bones of some *mammals* is considered sufficient, in the minds of most geologists, to war-

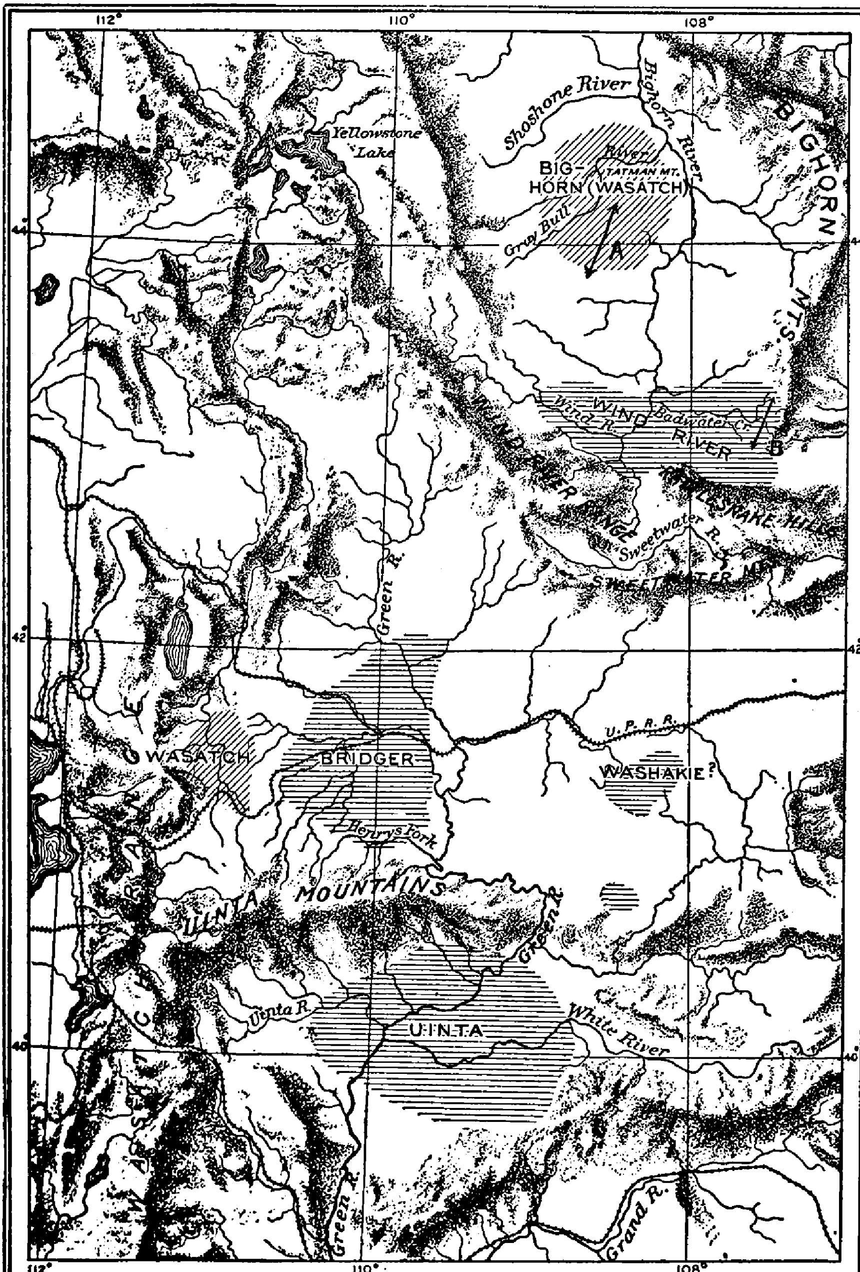

FIG. 362. Map of Southwestern Wyoming and Northern Utah, showing partial areas of the Wasatch, Wind River, Bridger, and Uinta formations. Extensive areas of the Wasatch are purposely omitted. (After H. F. Osborn and F. B. Loomis.)

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rant classing them with the Tertiary formations. Beds with very similar plants have been found in Greenland and Alaska.

In New Jersey (*Shark River beds*) are some marls and glauconite sands which rest upon Cretaceous strata. The *Medway* beds on the Gulf Coast, consisting also of glauconite sands, clays, and limestones, and also the *Wilcox* (*Lignitic formation*) beds, are classed as belonging to the lowest Tertiary.

On the western border between New Mexico and Colorado are two related series of beds (*Puerco* and *Torrejon*) containing bones of mammals, which unitedly are regarded as equivalent to the *Fort Union* beds. In Patagonia, beds have been found which contain the remains of mammals of the same grade as some of these beds from New Mexico and Colorado (*Puerco*); and these are regarded as also belonging to the "earliest" Tertiary, or the Paleocene. In Europe, extensive areas in the south of England, Belgium, and the north of France have furnished mammalian remains so remarkably like the *Torrejon* as to make them equivalent. Similar beds have been found in Denmark, in Central Russia, in the Pyrenees, and in Egypt.

Fossils are not very abundant in these rocks, all of the most distinctive types of both the Cretaceous and the Middle Tertiary being absent. Low or "primitive" types of *mammals* are the most characteristic types; or perhaps it would be more correct to say that those beds which do not show any distinctive Middle Tertiary mammals or invertebrates, but which instead show only certain "generalized" or "primitive" types of mammals, are classed as Paleocene.

Eocene Series

Distribution. Along the lower Atlantic and Gulf borders are many beds classed as Eocene. In New Jersey, Maryland, Virginia, and the Carolinas, they consist of unconsolidated sands and clays, with some *greensand* (glauconitic); and in general, it may be said that they here compose the surface beds and dip gently toward the ocean. On the Gulf border, and extending around the Mississippi embayment as far as Texas, are larger beds, some of which are quite hard limestones, sandstones, and shales, with extensive deposits of brown coal, or lignite. Some of these deposits (*Jackson formation*) contain the massive vertebræ of the extinct whale, *Zeuglodon*, in such vast numbers that in Alabama they were long "used for making walls, or were burned to rid the fields of them" (Dana), these vertebræ being a foot and a half long and a foot in diameter.

Whales and other large sea animals sometimes become stranded in modern times, on the sand of the shore; but here

we are not dealing with one or two individuals, but with great numbers. The catastrophic nature of the event evidenced is well stated by the Nestor of American geology:

"Vertebræ were so abundant on the first discovery in some places that many of these Eocene whales must have been stranded together, in a common catastrophe, on the northern borders of the Mexican Gulf,— possibly through a series of earthquake waves of great violence; or, by an elevation along the sea limit that made a confined basin of the border region, which the hot sun rendered destructive alike to zeuglodons and their game; or,

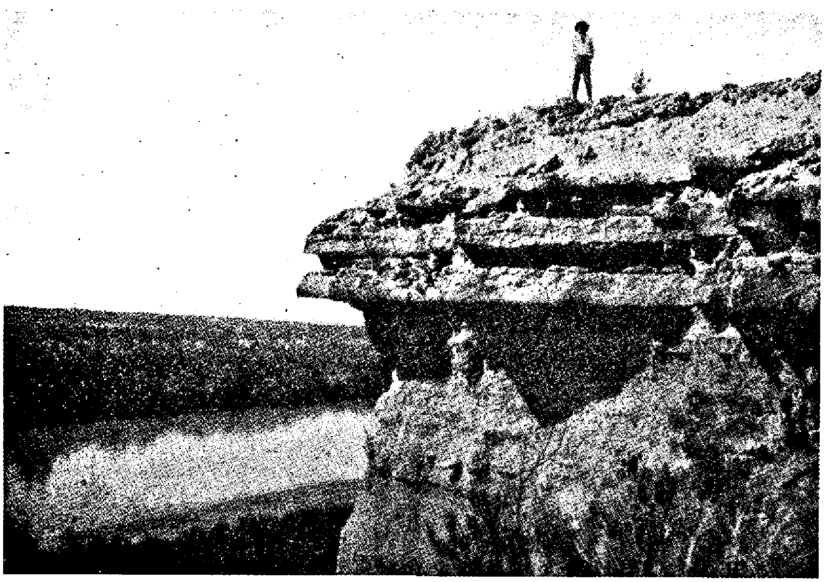


FIG. 363. Projecting ledges of Eocene limestone resting on Cretaceous shale, at White Bluff, Rio Grande, Texas. The strata are conformable. The Eocene strata are well consolidated. (Stephenson, U. S. G. S.)

by an unusual retreat of the tide, which left them dry and floundering for many hours under a tropical sun."— *Dana, "Manual," p. 908; edition of 1894.*

On the Pacific coast, the Coast Range shows Eocene rocks along its eastern flank (*Tejon*). The plateau region west of the Rocky Mountains shows an astonishing number of Eocene beds, some of which have become famous all the world over for the bones of mammals which have been unearthed from them. Of these Eocene deposits, the *Wasatch formation* is found from New Mexico, over wide areas in Eastern Utah and Western Colorado, to the Uinta Mountains, and by a narrow band extending northward and expanding so as to cover Southwestern Wyoming. Much of the Big Horn Mountains is composed of Wasatch beds. By some, these Wasatch beds are classed as

FIG. 364. Fort Union conglomerate (L. Eocene), 5 miles south of Meeker, Colorado. Here also the Eocene beds are as well consolidated as any of the so-called "older" formations. (Stanton, U. S. G. S.)

Paleocene, because of the low grade of the mammals which they contain.

The *Wind River* and the *Green River beds,* and also the *Bridger beds* of the same areas, are names applied to other wide areas in this plateau region. The first of these series contains a large number of mammals; the second, numerous plants, insects, and fishes; while the third contains the remains of fishes, crocodiles, and shells, mixed up largely with volcanic ash. These Eocene deposits of the plateau region comprise sands and clays, with occasional conglomerates; they are only partly consoli-

dated; and in this semiarid region, they usually weather out into the fantastic erosion forms known as the *bad lands*. Tapirs, giant pigs, titanotheres and uintatheres, which are quite extinct mammals, and also rhinoceroses, comprise a few of the many very extraordinary fossil mammals which have been brought to light from these great beds, which seem to have been literally Eocene graveyards.

In the Old World, the Eocene comprises wide areas of the most important mountain regions stretching across Europe and Asia. The characteristic rocks through this area are the *nummulitic limestones,* made up of the shells of *nummulites,* which were Foraminifera of the size of one's finger nail. Such limestones stretch through Southern France, the Pyrenees, Spain, much of the Alps, and eastward to Asia Minor. They occur extensively in the Apennines and the Carpathians; also in Egypt, and the pyramids and the Sphinx were made of this nummulitic limestone, the shells sticking out by differential erosion on the sides of the latter, and being known as "Pharoah's beans" by the Arabs. These nummulitic limestones extend over vast areas of Persia, Afghanistan, the Himalayas, and also in Japan, the Philippines, Borneo, and Java.

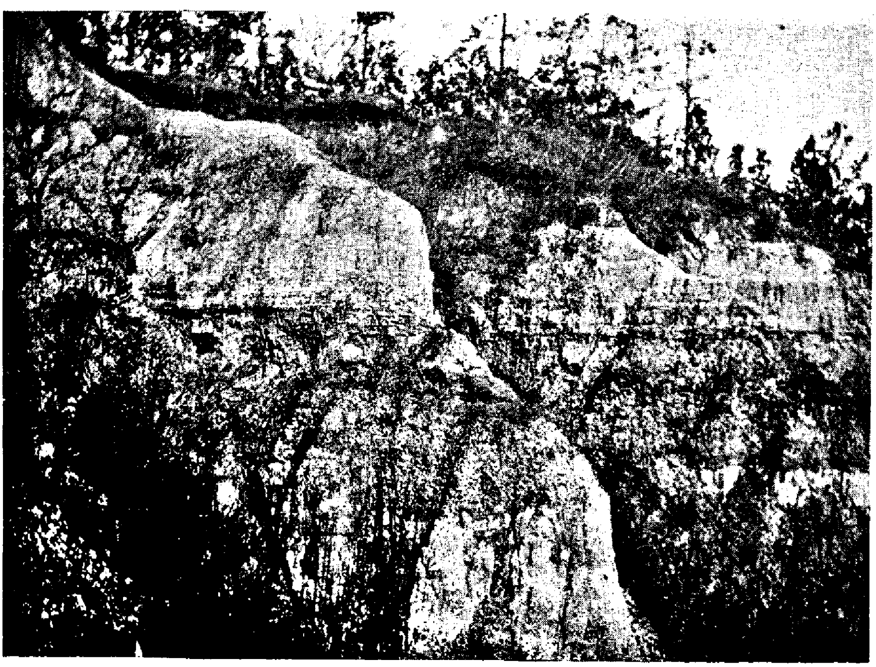


FIG. 365. Upper Jackson sands (U. Eocene), Siwel, Mississippi. (Crider, U. S. G. S.)

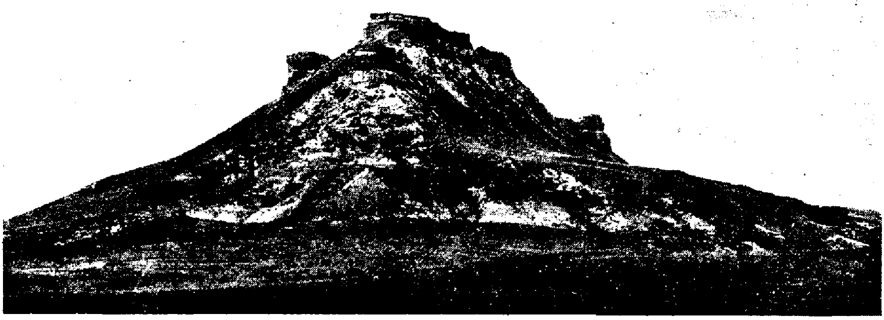


FIG. 366. Castle Rock, 30 miles northeast of Bellefourche, South Dakota. From the southeast. Tertiary sandstone resting on Laramie (U. Cretaceous). (Darton, U. S. G. S.)

Floras and Faunas. The *flora* of the Eocene beds has a very modern appearance; but it shows warm-climate or even tropical varieties in what are now comparatively severe climates. Through Idaho, Wyoming, Montana, and Canada are found such plants as oaks, willows, beeches, myrtles, poplars, elms, laurels, magnolias, maples, walnuts, pines, spruces, but also bananas

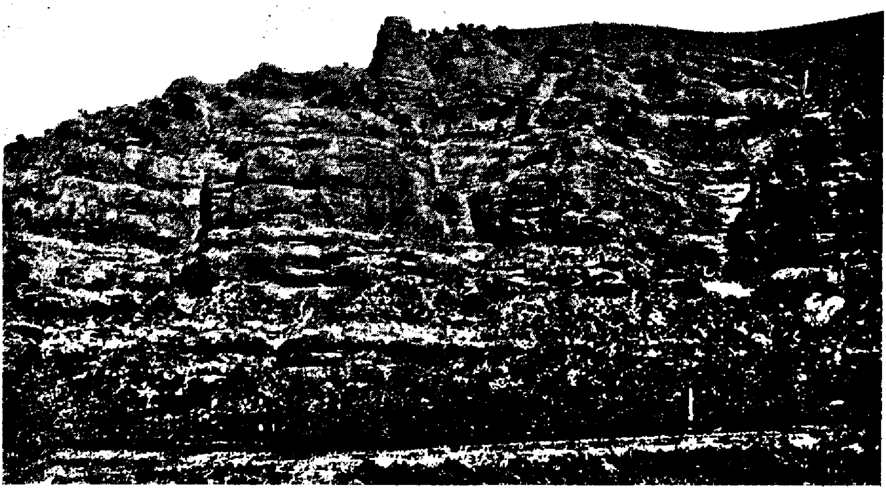


FIG. 367. Eocene conglomerate cliffs, near Echo, Utah. (Stanton, U. S. G. S.)

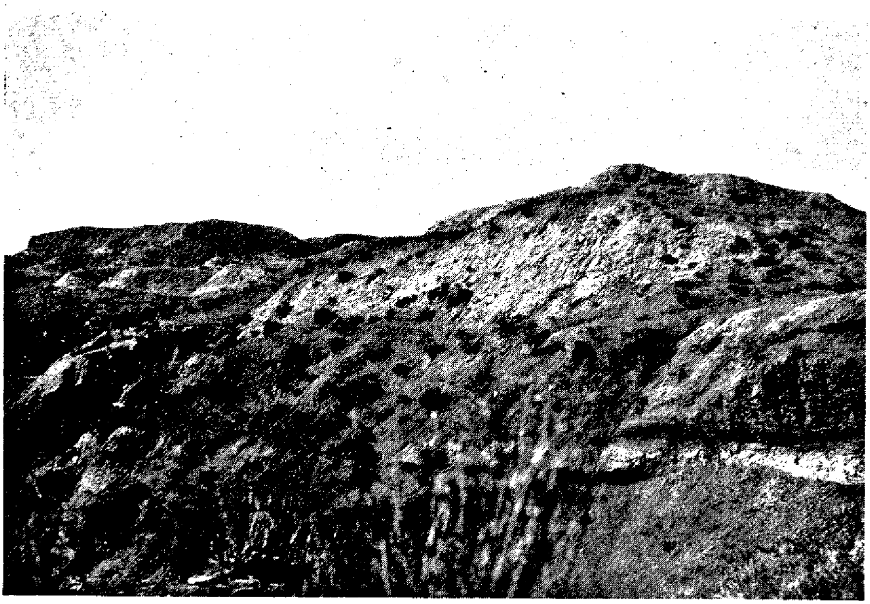


FIG. 368. Coal bed near the base of the bad lands near the mouth of Salt Creek, Wyoming. Fort Union formation (L. Eocene). The sandstone parting in the coal thickens rapidly toward the east, and becomes a thick bed of sandstone. (Stanton, U. S. G. S.)

and palms, with very many others. Many of these have also been found in the Eocene beds of Alaska and Greenland.

In Europe, the Eocene beds show an even more tropical aspect. Here *sequoias, gingkos,* with aloes, pines, and screw pines, occur along with the more temperate-climate forms already mentioned.

Of the animals, the genus of foraminifers known as *Nummulites* has already been mentioned. A related genus, *Orbitolites,* occurs in the Eocene rocks of the Gulf border in America. Corals like our modern corals are plentiful, while all the various kinds of shellfish are well represented. The fishes and the reptiles are essentially like the modern living ones. Some large flightless birds are also found. But it is the *mammals* to which especial attention must be given.

The great variety of mammalian forms found in the Eocene rocks has furnished the opportunity to mark off these rocks in successive stages, each stage characterized by its own peculiar type of mammalian life. But after these typical fossil mammals have thus been *used as index fossils* to determine the order in which the scattered formations should be arranged, it is very strange reasoning to take the results of this artificial

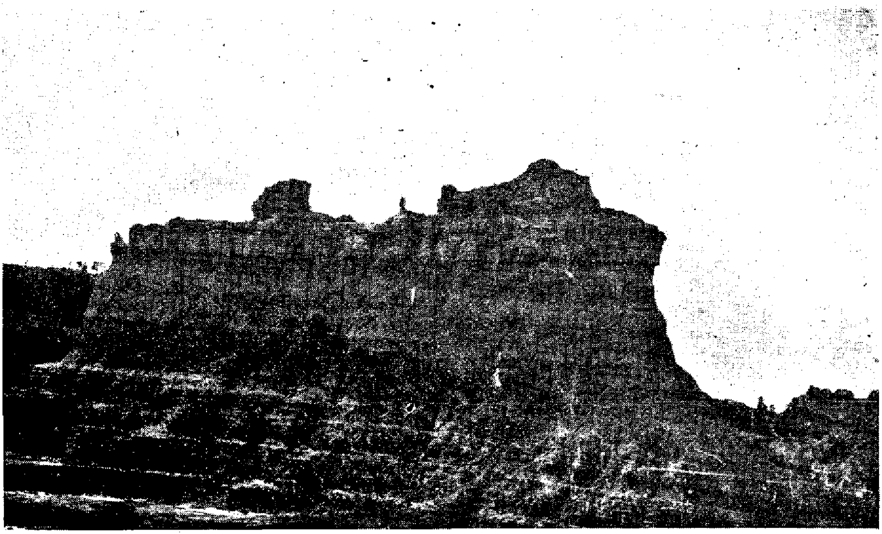


FIG. 369. "Ship Rock," near Reva Gap, South Dakota. A peculiar erosional form composed of White River strata (Oligocene). (Hares, U. S. G. S.)

arrangement as *evidence* regarding the precise order in which such forms as the horse, the camel, and the elephant *have evolved*. Why should our museums still be disgraced with such unscientific methods of "proving" a pet theory?

A great many curious forms, called "horses," or "pigs," or "elephants," by courtesy, because somebody can detect *some resemblance* to these modern forms in these strange creatures, are found among these Eocene rocks. But they are of interest mainly to those who think that by the circular reasoning alluded to above, they can trace back the pedigree of these modern mammals to their primitive originals. Of more interest from the point of view of real science are such bizarre forms as *Eobasileus* (Fig. 440), a creature with a body about as large as that of an elephant, with huge postlike legs, a low, flat skull with six horns upon it,— two on its nose, one over each eye, and one over each ear. It had two tusks or canine teeth projecting from the upper jaw; and from its diminutive brain, it was probably a creature of slow, dull movement that may have passed an inoffensive life browsing off the shrubs and trees where it lived. There is nothing like it alive to-day.

The Oligocene Series

Distribution. On the Atlantic coast, the Oligocene is very scantily represented; but on the Gulf border are thick beds containing a profusion of invertebrate life. Many of these rocks

are also found in the West Indies and in Central America. On the Pacific coast, they are extensively shown in Alaska, where they contain thick beds of lignite, also down the coast of British Columbia, and in Oregon. The famous *John Day beds,* which cover much of the eastern part of the latter State, and also a small patch in Central Montana, are classed as Oligocene. Immense lava outflows in the Columbia and Snake River region are referred to this series.

But as before, with the Eocene, the great interior region is where these rocks are best shown. The *Uinta* is sometimes classed as Eocene, but more usually as Oligocene; it gets its name from the mountains on the border of the Great Basin. The *White River formation* covers a wide area over several States of this region. These beds also have been very fruitful hunting grounds for the museum collectors.

Large lignite or brown coal beds in Belgium and Germany are classed with this series. Similar lignite beds are found in Russia and France, in Switzerland, and in Bavaria. The gypsum beds near Paris are classed here. Also the peculiar formation known

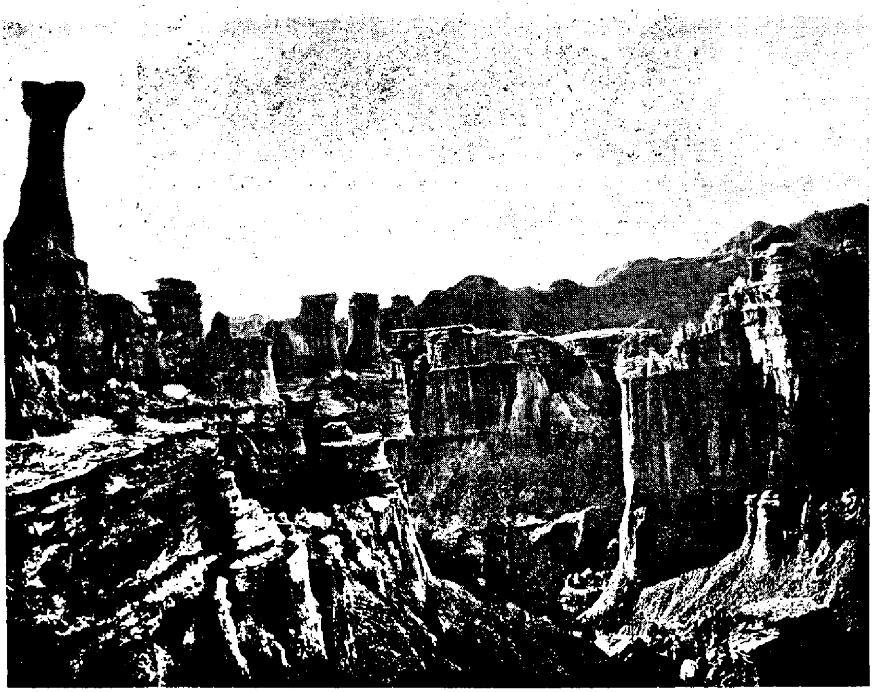


FIG. 870. "Protoceras sandstone" (U. Oligocene) area, Big Bad Lands, South Dakota. Characteristic erosion forms. (Darton, U. S. G. S.)

as the *Flysch,* a coarse deposit of angular fragments, is classed as part Eocene and part Oligocene. It is found in the Alps, the Apennines, the Carpathians, the Caucasus, Asia Minor, and in many parts of Southern Asia.

In most parts of the tropics, the Oligocene has not been separated from the series before and after it.

The *Uinta beds* have given us the great *uintatheres,* rhinoceroses, tapirs, and camels, with large and numerous crocodiles. The *White River beds* contain a very different fauna, which in-

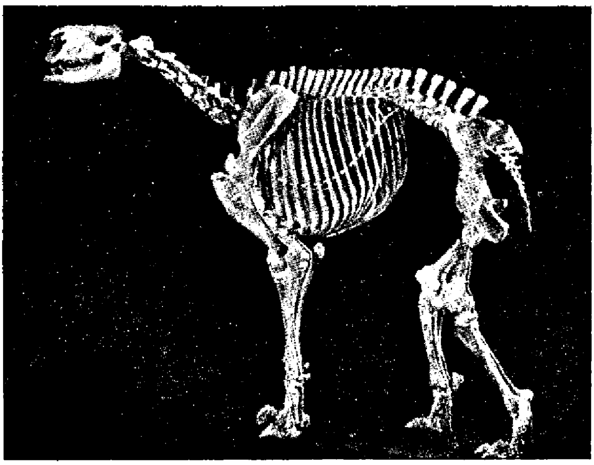


FIG. 371. *Moropus,* a remarkable ungulate nearly as big as a horse, with claws instead of hoofs. Oligocene and Miocene of North America. According to the fashionable method of reasoning, this animal was "undoubtedly" descended from the birds.

cludes many Carnivora, such as dogs, saber-tooth cats, and also the *Mesohippus,* an animal about as large as a sheep, and the monstrous *Titanotherium,* and many allied animals.

The peculiar group of hoglike ruminants called *oreodonts* were very abundant, with many small rodents, like squirrels, mice, rabbits, and beavers.

The Miocene Series

Distribution. Traces of Miocene beds are seen in New Jersey and Maryland, and from there southward. To the north of this area, they consist of unconsolidated clays and sands; but at Richmond, Virginia, they show also diatom ooze; while in Georgia and Florida, they contain compact limestones.

On the Pacific coast, the Miocene beds attain a great thickness and a wide extent, though chiefly in a long belt parallel with

the coast. Here the *Monterey formation,* comprising much of the Coast Range and the Santa Cruz Mountains south of San Francisco, is highly metamorphosed, and in appearance is remarkably like the greatly contorted Paleozoic rocks. At *Lompoc,* in Santa Barbara County, is an interesting set of beds composed

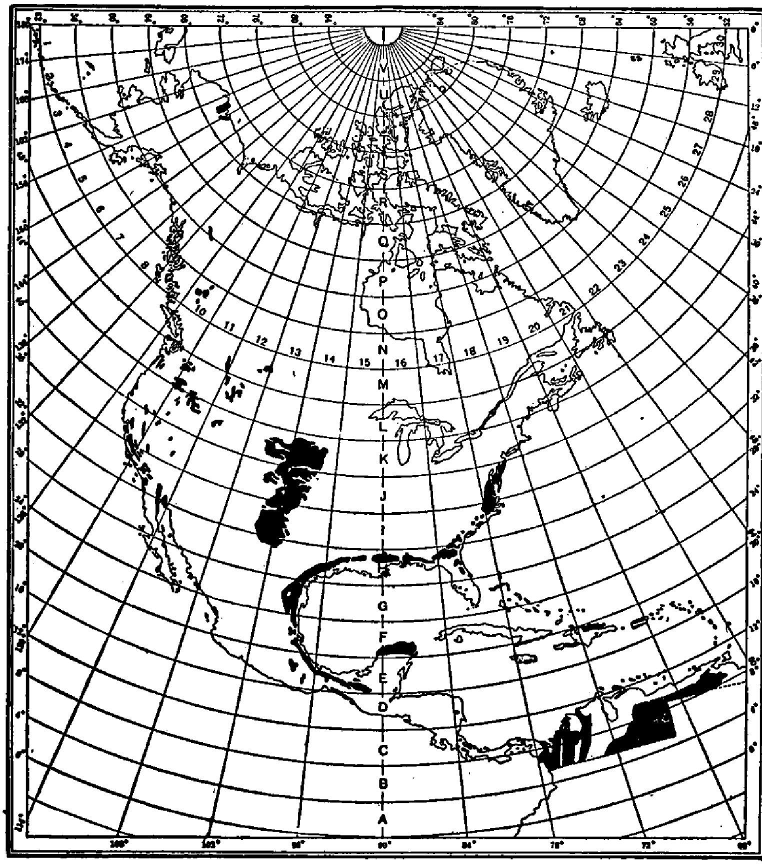


FIG. 372. Map showing the outcrops of the "later" Tertiary rocks (Miocene and Pliocene) in North America. (After Bailey Willis, U. S. G. S.)

almost entirely of diatoms and Foraminifera, but packed full of fossil herrings which have evidently been buried suddenly by this diatomaceous mass pouring down upon them before they could get away. Some four square miles of these beds have been left; the rest (nobody knows how much more in area) have been eroded away. The organic remains from these diatoms, fish, and other sources, are supposed to have been the

origin of the vast petroleum deposits found in the Coalinga district and elsewhere in the Tertiary beds of this State.

Wide areas in the interior of the continent which are of slight thickness, and which seem to have been formed from the erosion of the older beds of the present land surface, have been referred to the Miocene; but some of them are clearly not older than the Recent. The wide basaltic outflows on the Columbia and Snake have been called Miocene; but they may belong to the Recent period. The *Florissant beds* of Colorado, famous for their fossil insects and fossil plants, are called Miocene. More than a thousand species of insects have been described from these beds, which are largely the result of the dust from explosive volcanoes.

In Europe, no Miocene occur in England or in many parts of Northern Europe. In France, Spain, and Portugal, however, they occur; while very extensive Miocene areas are found in Italy, Sicily, and much of the northern part of Asia Minor. They are found in North Africa, in Northwestern India, in Burma, Japan, and Java. Patagonia, in South America, has large Miocene areas; and certain Tertiary beds of Australia and New Zealand have been classed as Miocene, because they contain fossils much like those in Patagonia.

Fig. 373. Restoration of giant pigs, *Elotherium* (*Entelodonts*), which were common in the Middle Oligocene of Europe and America. They had stilted legs and elongated skulls, and the entire body was of larger proportions than in the pigs of to-day. (Courtesy of American Museum of Natural History.)

FIG. 374. Skeleton of a horse, in Vaquero (L. Miocene) sandstone, Santa Barbara Cañon, California. This skeleton was situated in a vertical wall. (English, U. S. G. S.)

Fossils. Oaks, elms, beeches, maples, poplars, walnuts, hickories, magnolias, and sycamores are a few of the common trees found in the Miocene of Oregon and Yellowstone Park. Conifers also are abundant in these and equivalent beds, and these conifers include the *Sequoia,* or California redwood. All these trees have likewise been found in the Miocene of the arctic regions. In Oregon is also found the breadfruit, with palms in British Columbia. In Europe, the flora is even more tropical in aspect, resembling the modern flora of India.

The marine *invertebrates* are much like the present ones found in the warm waters of the south. *Birds* are always scarce as fossils, and very few have been found in the American Miocene; but in Europe, the birds of this series resemble the ones now found in Africa, including parrots, flamingos, ibises, and secretary birds, with many others that resemble the present birds of Europe.

The *mammals* of the American Miocene include wolves, panthers, saber-tooth tigers, camels, and many rhinoceroses.

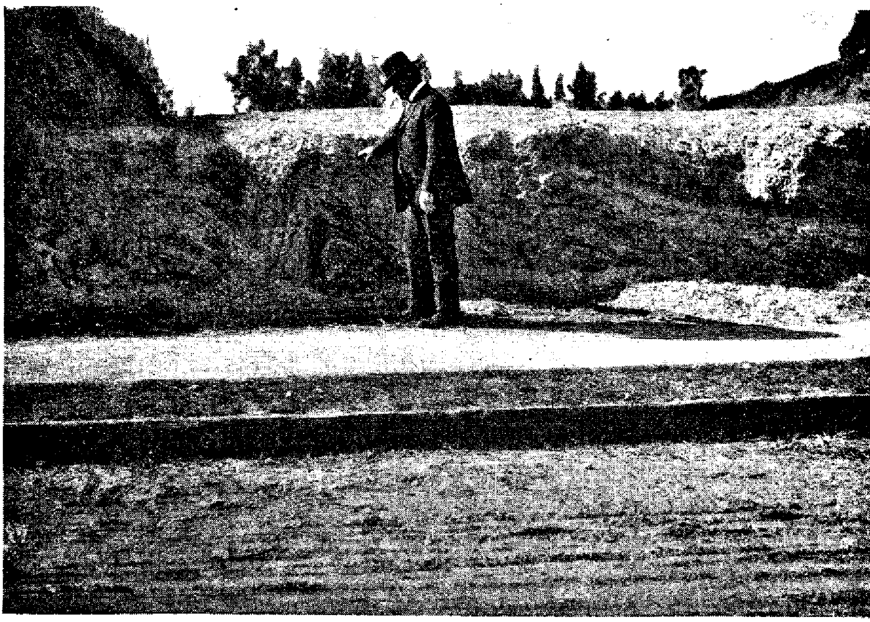


FIG. 375. Distorted Miocene shales, in a street car cut, in the northern part of Los Angeles, California. (Arnold, U. S. G. S.)

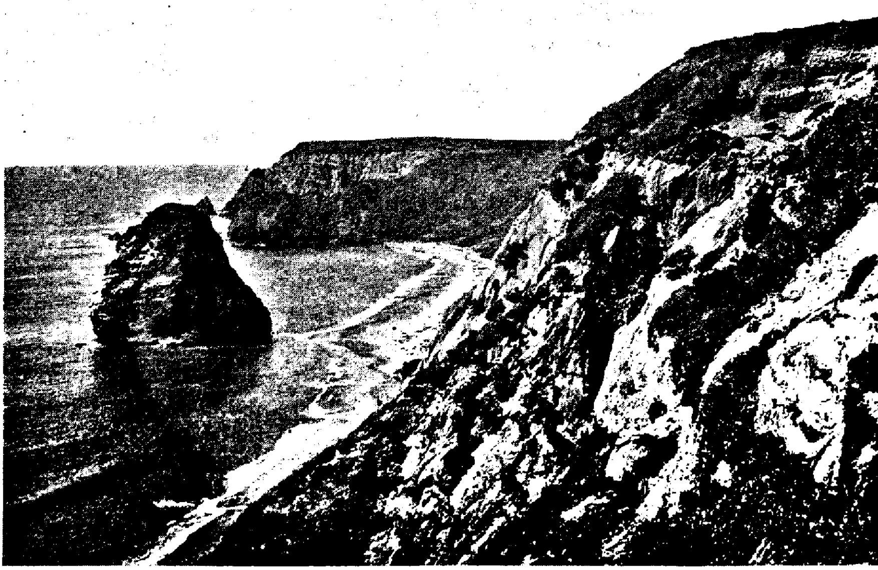


FIG. 376. Fin Rock and Cape Blanco, Oregon. Cape Blanco is composed of Miocene rocks. The rocks composing the ridge between the spectator and the cape, are Cretaceous. (Diller, U. S. G. S.)

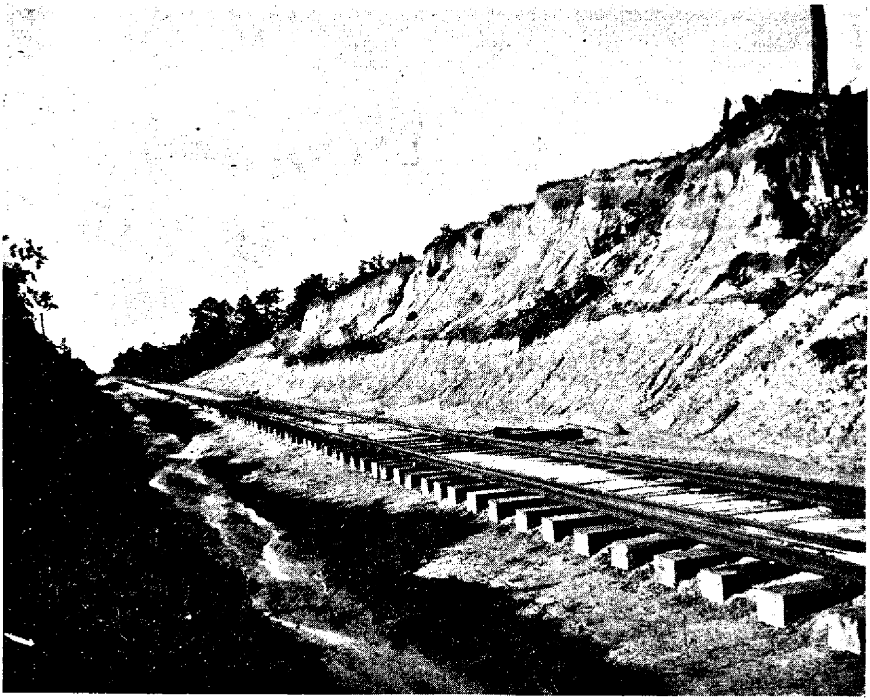


FIG. 377. Lafayette sands (Pliocene) resting upon purple Potomac clays (L. Cretaceous). In addition to the puzzle of the great stratigraphical gap between these two formations, the question naturally arises, Why should these Cretaceous beds be still so entirely unconsolidated? (Fuller, U. S. G. S.)

One species of camel-like animal, *Alticamelus,* was much like the giraffe in proportions. The horselike animals of the *Loup Fork beds, Protohippus* and *Hipparion,* are small but very interesting animals, often pointed to as among the ancestors of the modern horse. They had three toes on each foot. Peccaries, or wild pigs, are very common in the same beds. The European Miocene strata include much the same animals, also the peculiar elephantlike *Dinotherium,* with a flattened head, and two large tusks in the lower jaws which curved backward like massive hooks. Animals resembling the *mastodon* are found in both Europe and America.

The Miocene mammals of most of the other continents have not been well worked out. But in the *Santa Cruz beds* of Patagonia have been found a very interesting array of strange mammals. They include carnivorous marsupials, like the modern ones of Australia, with others resembling the phalangers of the same region, and also the American opossum. Rodents similar

to the South American porcupines are common, with armadillos, glyptodonts, and ground sloths; but the other animals commonly found in the North American beds are absent.

The Pliocene Series

Distribution. A few isolated patches of Pliocene beds have been recognized in Florida, Georgia, the Carolinas, and Virginia.

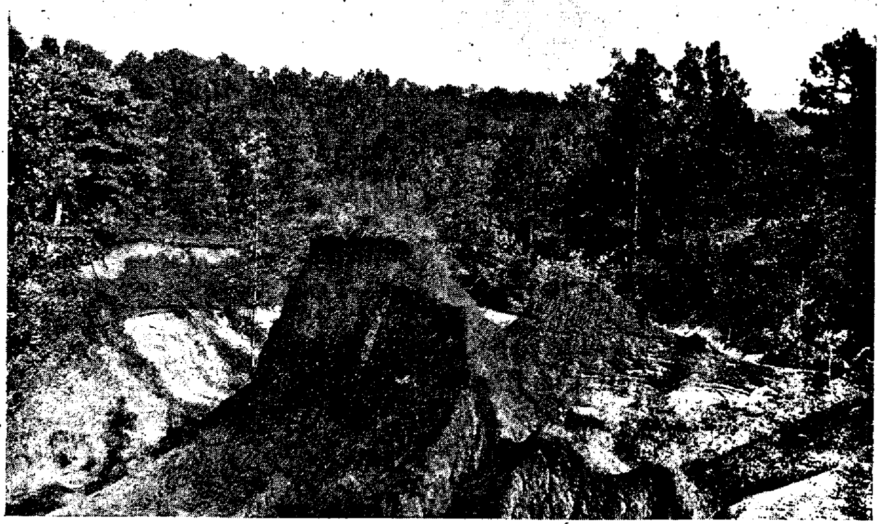


FIG. 378. Erosion gullies in Lafayette formation (Pliocene), about 2 miles northwest of Oxford, Mississippi. The beds consist of thin, reddish, irregular sandy strata, with whitish clayey sand. (Shaw, U. S. G. S.)

One small set of sands on the island of Martha's Vineyard are classed as Pliocene. Parts of Eastern Mexico, with much larger portions of Yucatan and Central America, are referred to the Pliocene.

On the Pacific coast, the Pliocene strata extend in a narrow strip (with many interruptions) through Washington, Oregon, and California. The Coast Range is partly Pliocene; while thick beds of sandstones and volcanic materials south of San Francisco (*Merced formation*) are also referred to the Pliocene; though some contend that the upper strata of these beds should be called Post-Tertiary, or Quaternary.

Small areas in various parts of the interior of the continent have been described as properly Pliocene. The *Republican River* formation is found in the northwest part of Kansas, Northern

Nebraska, and Eastern Oregon. Similar areas occur in Oregon and in Northwestern Texas, mammals like those of South America having been found at the latter place. "No doubt much of the surface deposit of the Great Basin and other regions is Pliocene, but lack of fossils prevents their determination." (Scott.) Very many of the great volcanic outflows (fissure eruptions) of Northern California, Nevada, Southern Idaho, and Eastern Oregon and Washington, have been referred

FIG. 379. Tertiary bluff, 3 miles east of Jines, Texas. (Gould, U. S. G. S.)

to the Pliocene and Miocene, as they lie upon beds classed as Lower or Middle Tertiary. But it is more than likely that most of these should be classed as *Recent*, or even later than the Pleistocene, as most of the outflows of this character occurred after most or all of the sedimentary beds were laid down.

In Europe, the Pliocene beds are shown in Belgium and Northern France; though larger areas occur in Spain, and Algeria, and very much of Italy and Sicily, and also of Greece, are classed as Pliocene. The *Pikermi beds* near Athens, with the island of *Samos*, are famous for their mammalian fossils. Beds of lignite occur in different parts of Germany, in some of which the plants "are nearly one half conifers, but also include many American trees, such as walnuts and hickories." (Scott.)

Extensive beds on the south side of the Himalayas (the *Siwalik Hills* formations) have become noted for their remarkable fossils; while very similar fossils have been found in Borneo

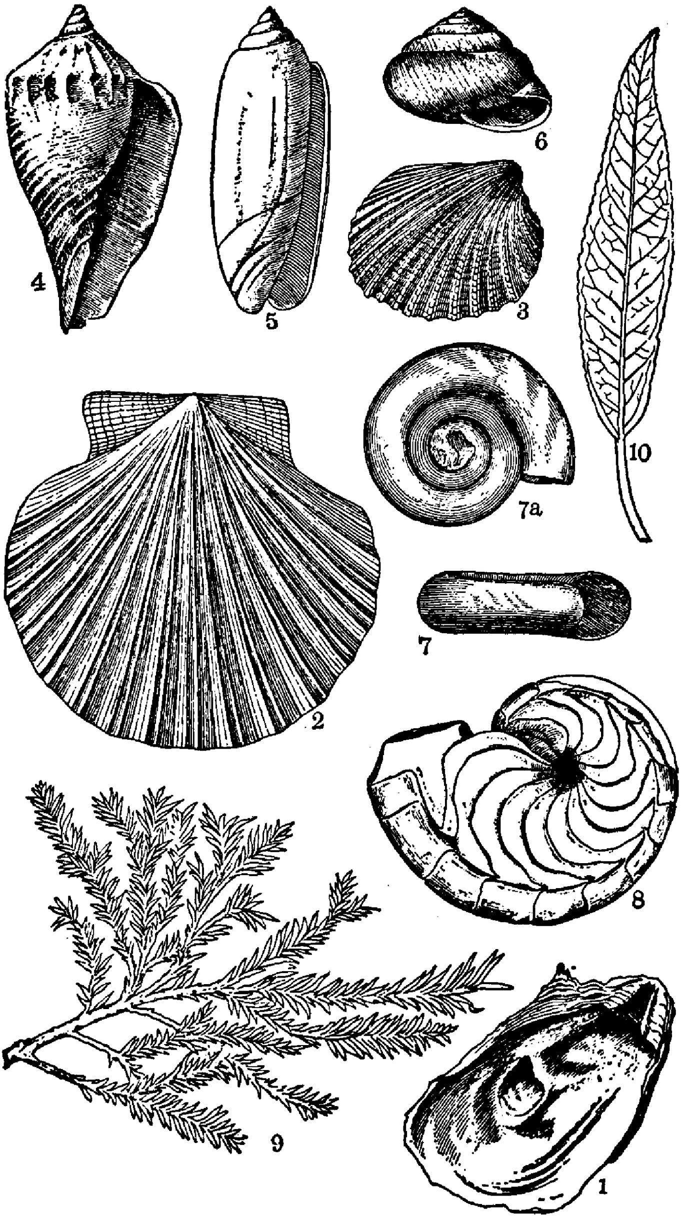


FIG. 380. AMERICAN TERTIARY FOSSILS

1, *Ostrea virginiana*, × ½, Miocene. 2, *Pecten madisonicus*, × ½, Miocene. 3, *Cardita perantiqua*, Eocene. Whitfield. 4, *Volutolithes sayana*, × ¾, Eocene. 5, *Oliva carolinensis*, × ¾, Miocene. 6, *Helix dalli*, Miocene. White. 7, *Planorbis convoluta,?* Fort Union. Meek. 8, *Aturia vanuxemi*, × ¼, Eocene. 9, *Glyptostrobus ungeri*, × ½, Eocene. Lesquereux. 10, *Salix* sp., × ¾, Miocene. (1-5, and 8, after Whitfield.) (After W. B. Scott, "Introduction to Geology," permission of Macmillan Co.)

and Java. Pliocene strata have also been recognized in Argentina and Patagonia, South America.

Fossils. Very few plants or trees have been found in the Pliocene beds of North America. In Europe, however, occur many trees which are now growing only in America or Asia,

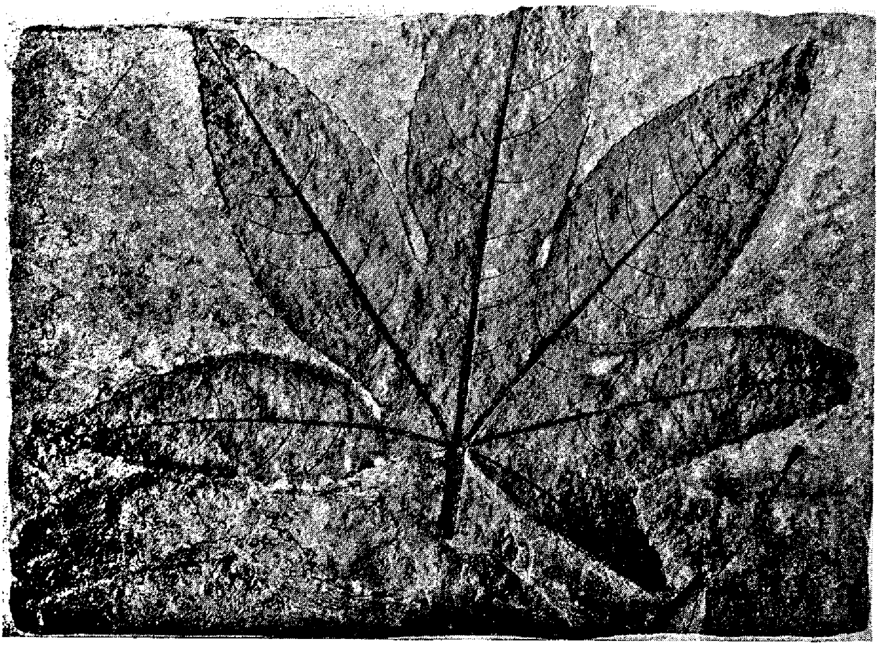


FIG. 381. Fossil leaf of the sweet gum tree, liquidambar, from a quarry in the Green River (Tertiary) formation, Western Wyoming. There are only two living or modern species, one from Asia Minor, the other from tropical America. (Lee, U. S. G. S.)

such as tulip trees, magnolias, walnuts, hickories, sequoias, and many others.

The marine *invertebrates* are practically those still living in the localities near where the fossils occur; but it should be remembered that only a very small fraction of the great numbers of genera and species found as fossils in the Mesozoic and Lower Tertiaries, and which are still alive in our modern oceans and on our modern lands, have been found as fossils also in the Pliocene. In other words, these multitudes of modern genera surviving from the so-called "older" rocks are (by this artificial arrangement) made to skip the Pliocene "Age," leaving no trace of their existence. Many of them seem to skip all of the Tertiary and the Pleistocene. All of which shows the absurdity

of saying that these Pliocene beds represent the life-forms of an "age" or "period" in the world's history.

The larger *mammals* are much like those already described from the Miocene, with species much more like the modern ones (for this is *why* they are classed as Pliocene). Mastodons, horses, camels, rhinoceroses, pigs, huge ground sloths, and armadillos, are some of the representative mammals found in the Miocene beds of North America. In Europe occurs also the *Dinotherium,* with the hippopotamus, the giraffe, and many others. In the *Pikermi* formation of Greece and the *Siwalik* of India occur the remarkable *Samotherium, Sivatherium, Bramatherium,* and other related forms, which were huge creatures like the giraffe, with four horns on their heads.

In volcanic tuffs which have been called Pliocene, on the island of Java, were discovered pieces of a skull, a femur, and some teeth which have been named *Pithecanthropus erectus.* These fossils have been much discussed, and have been called the oldest human remains known. Good authorities, however, have said that they are the bones of a large gibbon (*Hylobates*). It has also been denied that the strata in which these fossils occurred are really Pliocene. The truth seems to be that these materials are of that problematical character which leaves the decision regarding them largely a matter of personal preference; while the decision as to whether these beds should be called Pliocene or Pleistocene or Recent, is also very much a matter of personal opinion.

On the basis of the current theories regarding the successive geological ages, it is difficult to understand why we ought not to find abundant Tertiary remains over most of Northern and Eastern America, or over the other continents where no such remains are to be found at all. According to the current theory, these regions were mostly dry land during the Tertiary "era," and were densely populated with mammals, birds, and the various inferior orders of invertebrates. Why should we not expect to find abundant traces of their remains over these wide areas, instead of in the few scattered patches where we really do find them? Surely the few scanty traces of this profuse Tertiary life which we actually do find along the Atlantic coast and the Gulf border, as well as in a few isolated spots through the interior, are quite insignificant in allaying our curiosity, and do not help very much to remove the charge of absurdity which might be brought against this theory on this ground alone.

Methods. The great Cuvier was the first to make a scientific study of the fossil Tertiary mammals of the Paris basin. These bones had long been known, but were thought to be those of modern animals. Through careful study and comparison with the living forms, Cuvier was enabled to reconstruct the long disjected skeletons, bringing bone to bone as they were in life; and from observing the mutual dependence which subsists between the different parts of every skeleton, he was often enabled to determine the shape and character of the missing parts. His

FIG. 382. Palm leaf found in the roof of the coal mine at Cokedale, Colorado. Tertiary. The leaf is 36 inches wide. (Lee, U. S. G. S.)

happy hits at reconstructing an entire animal from only a few bones of a wholly unknown creature, revealed an almost prophetic insight into the nature of the parts which would some day be found, when more complete skeletons would be discovered; and these fortunate guesses have been repeated to wondering students ever since, with the accounts of the subsequent finding of just such animals as Cuvier had predicted. But his curious mistakes along this line are not so generally remembered; while his fantastic speculations regarding the alleged "order of creation," as revealed in the strata, have acted like a pathologic taint in the whole subsequent history of the natural sciences. A great man, a wonderful man, under whom most astonishing progress was made in understanding the fossil animals and even

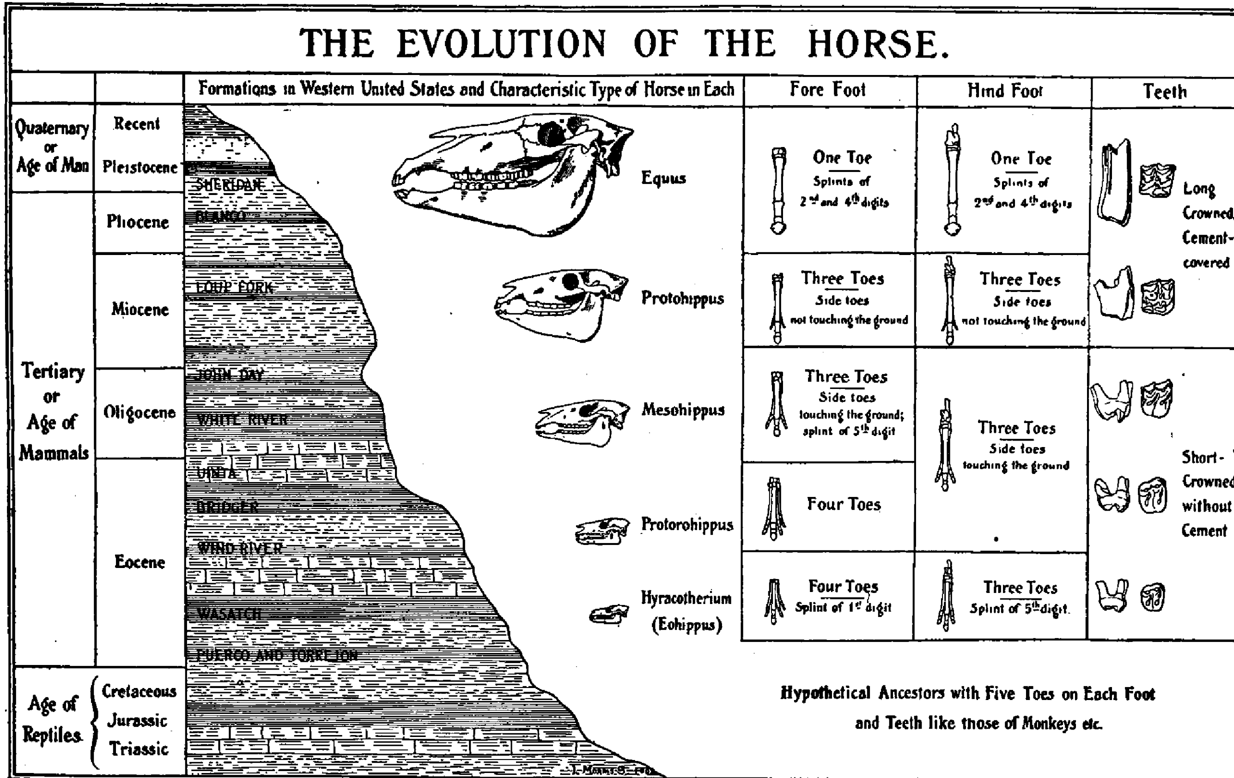


FIG. 383. One of the important facts to bear in mind when exam ning such a diagram as this, is that the formations here represented as superimposed upon one another, are not found thus in nature,—this is a purely artificial arrangement, made up from widely scattered formations, with nothing whatever of actual fact to forbid the idea that all these so-called "horses" were really living contemporaneously. Even the modern horse, *Equus*, is also found as a true fossil, along with the others, and became extinct in America (as far as we can tell) at the very same time as all these other animals, with the mammoth also, and the rhinoceros, the camel, the saber-tooth tiger, and the megatherium. This is a purely artificial table, designed to deceive only the ignorant. It is reproduced from the publications of the American Museum of Natural History, New York City.

the living ones; yet the baleful effect of the theories initiated under the dominating spell of his influence has not yet been outgrown by either geology or zoölogy.

As already remarked, it has always been the intention of geologists not to include among the Tertiary species the fossils of any fishes, reptiles, birds, or mammals which can be shown to be identical with the corresponding living species. Hence new specific and often new generic names are given to the fossil species found in any of the Tertiary beds, though it is almost certain that in this way many gross mistakes have been made which tend to *cover up the real facts in the case*, and which create mountains of labor for those who wish to work out a sound science of the fossil forms.

Many thousands of new species and genera have also been created from the finding of only a few imperfect parts, in some cases only a few teeth or a single bone. And no allowance seems ever to be made for the influence of a very *marked change in environment* in bringing about an adaptive response in both animals and plants without effecting any real changes worthy of specific distinction. It is to be hoped that some day a truly scientific and unprejudiced comparison of all the Tertiary fossils, to say nothing of those of the Mesozoic and of the Paleozoic, with the forms now living, will be undertaken by somebody, so that we may really know the truth about this problem of "extinct species." At the present, however, this whole subject is a mass of utter confusion which no one has had the courage to attack.

CHAPTER XXXVI

The Quaternary System—The Pleistocene Series

Classification. Most geologists consider the Quaternary system as including but one series of deposits, called by various names: Pleistocene, Glacial, and Post-Tertiary. The last term is an awkward one, and emphasizes a *false distinction* between these beds and the Tertiary beds, a distinction which nowhere exists at all, except over the northeastern part of America and the northwestern part of Europe. The term "Glacial" is open to the second of the objections just presented against "Post-Tertiary," and it has also this additional objection, that it embodies in itself, in explanation of these deposits, a theory which some geologists do not believe, but stoutly deny. The term "Drift" was also used by the early geologists; but this term was discarded by the glacialists for the same reason that some are now repudiating the term "Glacial"— because it has too much theory in it. The term "Diluvium" was similarly used by the geologists of the first part of the nineteenth century, and similarly discarded by those of the last part of the same century. Geologists like the present writer, who deny any time-value as attaching to the fossils *per se,* might reasonably object to the terms *Quaternary* and *Pleistocene,* as embalming the ideas of a discarded hypothesis. Yet we *must have some name* by which to designate these strata; and when all things are considered, probably the terms at the head of this chapter will be the least objectionable. They have also the merit of being almost universally used by modern geologists, though the term "Glacial" is almost as widely used as an equivalent term.

Attention should also be called to the need of grouping these formations *with the Cenozoic group,* thereby expressing their proper classification as being included with the Tertiary beds among the deposits of true geological age, and marking off all of these deposits from the "Recent," or the "Modern," from which they are in all parts of the world *clearly and sharply divided.* This puts the *great hiatus* or dividing line between the true geological and the Recent where it properly belongs. And it is well to note that this method of classifying these formations is followed by all the older geologists, including Dana, as well as many of the modern ones, such as Scott and Schuchert;

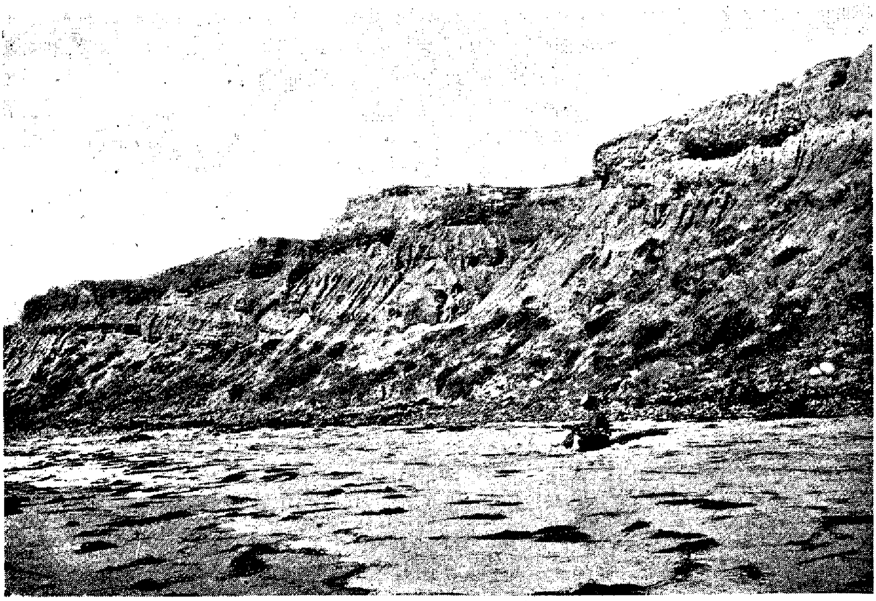


FIG. 384. Cliffs showing the contact line between the Pliocene and the Pleistocene beds, Pacific Beach, 10 miles north of San Diego, California. The Pleistocene beds on top are quite remarkably consolidated. This contact shows an angular unconformity. (Arnold, U. S. G. S.)

though other methods of classifying them are also given in some textbooks.

Following our usual custom, we shall first state the occurrence and the character of the deposits included in the Pleistocene, then give a statement of the kinds of life represented, and afterwards discuss the theories attached to the explanation of these phenomena.

Occurrence. Throughout Canada and the northeastern United States are very many scattered localities (assumed to have been once *continuous* and since removed in places by erosion) where occur what are called *bowlder clay* or *"till,"* an unstratified (generally) mixture of clay, angular fragments, pebbles, and bowlders, some of the last-named being very large. Some of these bowlders are now seen as "perched rocks" sitting on the tops of hills or other high spots of ground; and in some instances, they are as big as a haystack or a small house. Often these bowlders can be identified as having been derived from a particular locality where such material forms the country rock, this locality being sometimes many miles to the north; and such bowlders are then called *traveled bowlders.* These *bowlders,* large and small, are frequently found to be marked

with scratches or *striæ*, and are often polished or smoothed. Likewise some of the rock surfaces over which these materials (bowlder clay, etc.) lie are marked with striæ, while others are smooth and fresh-looking, or unmarked by weathering. Deep parallel flutings or grooves are sometimes found, which make the rock look almost like the finish on an enormous picture frame, these grooves having been made evidently by a hard substance which has been dragged over the rock surface with tremendous violence. To all this list of phenomena must be added

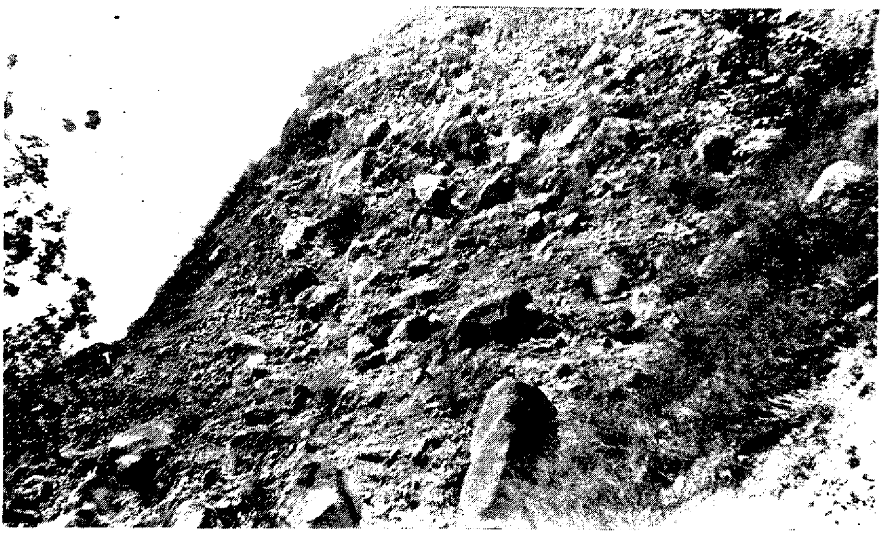


FIG. 385. Pleistocene conglomeritic valley fill, Pala, San Diego County, California. Why is this not called a "glacial moraine"? (Ellis, U. S. G. S.)

many peculiar forms of deposited materials, such as *kames, eskers, drumlins,* and so-called *moraines,* which have been described in a previous chapter.

Bowlders. The traveled bowlders which are so characteristic of these Pleistocene deposits, are of all dimensions from those of a small pebble to those of a good-sized house. Many on Cape Cod are 20 feet in diameter. One at Bradford, Massachusetts, is about 30 feet each way, and is supposed to weigh 2,000 tons. Some are even larger than this: the "Churchill Rock," at Nottingham, New Hampshire, is 62 feet long, and 40 feet wide and high, and must weigh about 6,000 tons. The famous "Pierre-a-bot," on the Jura Mountains, is also 62 feet long, but is 48 feet broad. Many other examples have become sufficiently famous to have received individual names. Certainly nothing but the most stupendous of forces could have

been adequate to the transportation of such masses into their present positions.

That they have actually been transported to the localities where we now find them seems self-evident when we examine their surroundings; for they are like strangers, being composed of kinds of rock quite different from any *ledge* of rock near by, the ledges from which they were apparently derived being usually a few miles or even a hundred miles or more away, and in a more or less northerly direction. This is as true of the small bowlders as of the large ones; *the land to the south seems to be now covered with stones from the lands lying to the north.* And all this evidently took place *after* all or almost all of the other geological changes; because these Pleistocene deposits are the *surface* rocks over the areas mentioned, being spread out indiscriminately over all the other formations.

FIG. 386. Traveled bowlder of coarse schist, transported at least 5 miles. Near Camden, Maine. (Bastin, U. S. G. S.)

Other Drift Materials. As already remarked, much of this drift material is apparently quite unstratified, the ingredients being mingled pell-mell. Some, however, is plainly stratified; and this stratified portion is scattered over all the areas here involved. Moreover, it is often so embedded in the other as to indicate that the latter also was deposited by water, but water in extremely violent action.

The whole of this transported material is called the *Drift* (very often called the "Glacial" deposits), while the unstratified portion is called the *till.* Among the latter, there is in many cases a peculiar mixture of clayey earth and angular stones, with numerous traveled bowlders. This is called the *bowlder clay,* though the term is sometimes used as synonymous with *till.* The actual clay of this deposit is often found to have thin, even layers within it.

Additional Facts. All these phenomena are commonly interpreted as having been due to the action of great glaciers of almost continental extent which formerly covered the areas here spoken of. But before we decide whether or not this interpretation is correct, other facts in connection with these which we have already mentioned, must also be enumerated.

1. In very many localities, more than one layer of till is found, the two layers being separated by materials plainly water-borne, among which are the remains of plants and animals which live only in mild or semitropical climates — such plants and animals as we have already described from the Pliocene and other beds of the Upper Tertiaries. Sometimes these *inter-tillite* (called "interglacial") beds are distinctly *marine,* containing animal remains found only in the deposits formed by the ocean, including oysters and other sea shells and even Foraminifera.

2. Most, probably all, of the striæ occur only on the surfaces of the older or nonfossiliferous crystalline rocks (Archæan).

3. The typical traveled bowlders are also invariably composed of the older crystallines, though fragments large or small of such formations as fossiliferous limestone may occur in the inter-tillite beds.

4. The limits covered (with many interruptions) by these Pleistocene deposits are of considerable importance in framing a true induction regarding the cause which spread them out. The areas involved extend down in a general way to the Ohio River in the eastern part of the Mississippi Valley, and to a

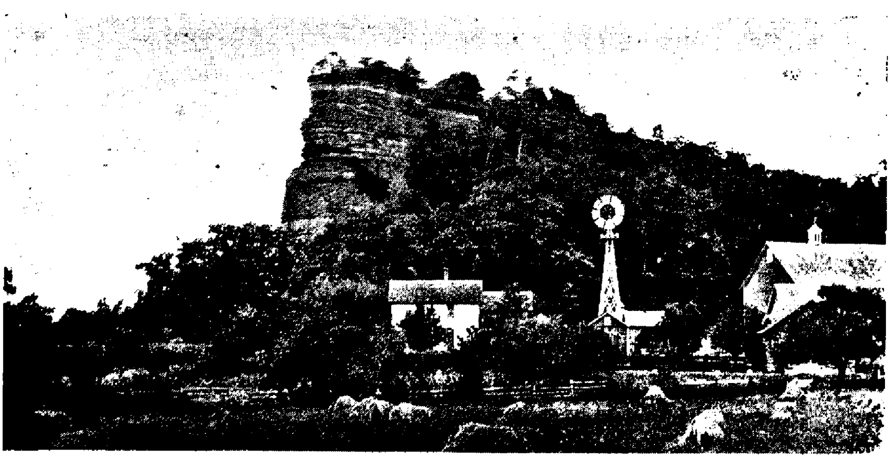


FIG. 387. Tower Rock, an erosion remnant of Potsdam sandstone (U. Cambrian), in the "Driftless Area," Wisconsin. (Alden, U. S. G. S.)

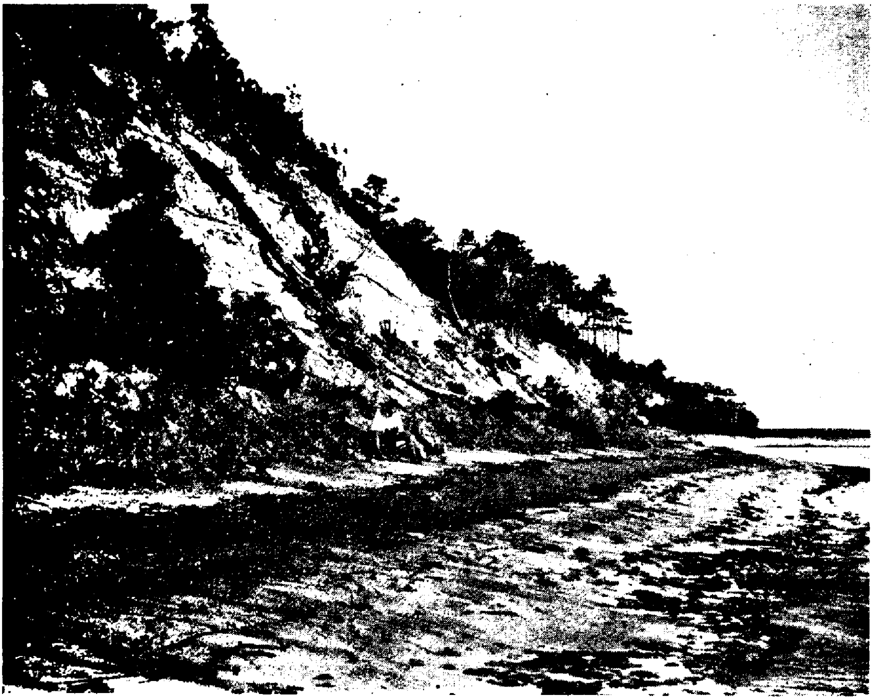


FIG. 388. Pleistocene bluff, right bank of the Cape Fear River estuary, about 2 miles above Southport, North Carolina. Blue Clay layer, with shell casts and much lignite, at base (? Cretaceous). (Fuller, U. S. G. S.)

little south of the Missouri River in the western part. Within this area is a large "*driftless*" area in the central part of Wisconsin (Fig. 387). But there are *no such deposits in Alaska,* and none west of the Rocky Mountains. In Europe, the areas affected extend down to the central parts of the Continent and to the Thames and Bristol Channel in the south part of England. They extend over the northwest part of Russia; but there are *none in Siberia, or east of the Ural Mountains.*

Such are the leading facts relating to the phenomena with which we here have to deal. It is quite unnecessary to say that these facts have proved the most perplexing, the most obstinately inscrutable, of any with which geologists have had to deal. Tons of books and pamphlets and scientific articles have been written about these phenomena during the past two or three generations, and the end is not yet in sight. But it would be quite beyond the scope of a chapter like this one to enter at length into the discussion of the perplexities of this subject. Here it must suffice to state briefly some of the conclusions which seem to be warranted by the facts as we now know them.

H. H. Howorth. The arguments against the glacial theory have been ably presented by Sir Henry H. Howorth, first in a long series of articles in the *Geological Magazine*, of London, and afterwards gathered into volumes, one entitled "The Mammoth and the Flood," two entitled "The Glacial Nightmare and the Flood," and two more entitled "Ice or Water." In these volumes, the author seems to make out a strong case, first, against the possibility of glaciers' ever being able to do the kind of work which we see in these Pleistocene beds; second, in favor of an abnormal sweep of waters as being the undoubted cause behind these phenomena. So far as I am aware, these elaborate and scholarly works of Howorth have never been answered, and have never been met in any adequate or detailed way; and until some such answer is forthcoming, we may consider his main thesis unanswerable, and needing no supplementary arguments here.

That in the Alps and other mountains, glaciers once existed of much greater extent than at present, is a fact easily susceptible of proof. But that a great sheet or great sheets of ice once spread over the "drift" areas in America and Europe, that this ice was competent to travel over hundreds or thousands of miles of level ground, and that it could dig out lake basins, erode river channels, and spread out the well-stratified materials constantly found associated with these other phenomena, seems utterly incapable of proof, and wholly incredible.

As for the elaborate distinctions made between the different deposits, with many "interglacial periods," etc., Howorth says he is a —

"complete disbeliever in any such separation, except as a mere local phenomenon. Whichever way we view the facts, they seem to point to these beds as representing different phases of *one movement representing one period of no long duration;* and the differences in the beds seem to mark, not the operation of different and widely separated forces, but the manifold handiwork of water which at one and the same time can and does lay down shingle beds in one place, sand banks in another, and mud in a third, according to the force and character of its currents. This view is not my own only, it is shared to a large extent by some of the most distinguished explorers of the glacial beds. They have pointed out that the same shells occur at all supposed horizons in them, that pockets of the same kind of sands and gravels are found embedded in the midst of the clays like plums in a pudding, and traversing and overlapping lines of junction and of bedding, and that the beds themselves are ranged in no certain order of sequence, but most irregularly, so that no kind of suggested arrangement suits any two localities."—*"Nightmare," pp. 843, 844.*

Regarding the idea of huge continental ice sheets, this author declares:

"I not only disbelieve in, but I utterly deny the possibility of ice having moved over hundreds of miles of level country, such as we see in Poland and Russia, and the prairies of North America, and distributed the drift as we find it there. I further deny its capacity to mount long slopes, or to traverse uneven ground except when under the impulse of gravity. I similarly deny to it the excavating and denuding power which has been attributed to it by those who claim it as the excavator of lakes and valleys; and I altogether question the legitimacy of arguments based upon a supposed physical capacity which can not be tested by experiment, and which is entirely based upon hypothesis."— *Id., Preface, pp. xiv, xv.*

Other Considerations. That the vast area of Northeastern America known as the great Canadian "shield" should have been above the ocean for the uncounted ages since Archæan time (according to the popular theory), without having its rocks weathered, and immense accumulations upon it due to this weathering — in other words, without showing everywhere deep *residual* materials, probably containing many relics of Mesozoic and Cenozoic life — is wholly unreasonable. But over this vast area, there is practically nothing in the way of such results from the disintegration of the bed rock. Instead, these basal rocks are covered with transported materials, and these transported materials often contain the remains of plants and animals so wholly strange and foreign to the present climate and general environment as to make an *abrupt break* between the two eras, the geological and the modern, instead of that gradual transition which it has been the business of uniformity to establish.

This, it seems to me, is the great subconscious reason for the popularity of the glacial theory: It furnishes a sort of mental buffer, an intellectual shock-absorber, enabling the uniformitarian to pass from that old world of so many wonders in plants and in animals, as well as in its climate, over to the modern world, with as little sense of catastrophe as possible. A few hundred thousand years of a recurrent glacial climate, or perhaps a million or two, make it easier to deny or ignore the *real abruptness* of the change from that ancient world to the modern one. And in this legerdemain, *time* is supposed to be the equivalent of power, and equal to the task of effecting any sort of transformation whatever.

Raised Beaches. There are other phenomena scattered over the whole globe which manifestly belong to this transition period between the true geological era and the modern. To this class belong the *raised beaches* around practically all the continents. In the high latitudes of the arctic, these old sea beaches or strands are often at considerable elevations, while

FIG. 389. The so-called "parallel roads" (terraces) of Glen Roy, Scotland. (After W. Lamond Howie.)

as a rule they are nearer to the present sea level in more southerly latitudes. San Pedro Hill, however, offers a good example of these phenomena. It stands at the southwest corner of the wide Los Angeles plain of Southern California, and is 1,000 feet high; and it has eleven distinct wave-cut terraces on its southern side, or the side facing the ocean, these being clearly old strand lines, and formed during the period when the lands and the oceans were taking on their present relationships.

Terraces. And the *high terraces* which are found along the valleys of almost all headwaters and mountain streams, tell

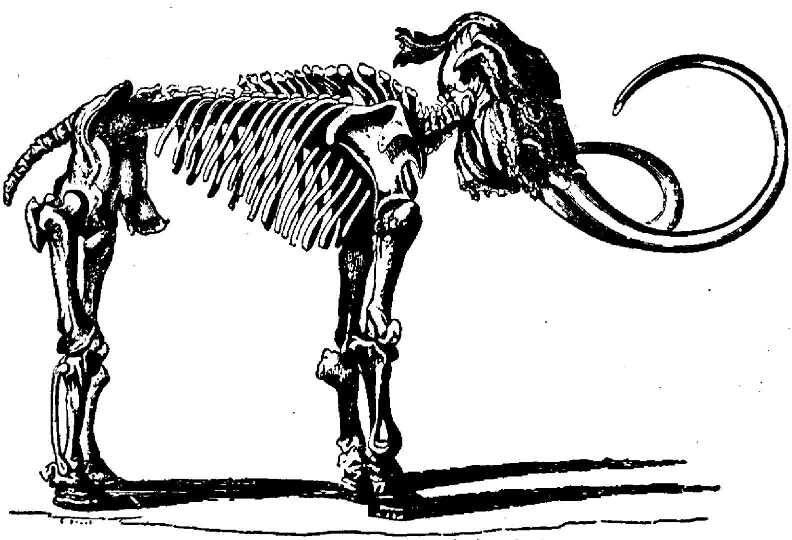


FIG. 390. Skeleton of mammoth (*Elephas primigenius*). (After d'Orbigny.)

substantially the same story. Many of these are in such positions that to bring flowing water up to the levels where we find them, would render necessary the submergence of almost whole continents. And of course it would be more convenient to suppose that vast glaciers had dammed back the waters, so as to render the formation of such terraces possible. But, unfortunately for this glacial theory, such high terraces are not at all confined to northern lands, but are found as well throughout tropical and semi-tropical regions. In fact, they constitute a world-wide series of phenomena which manifestly record the period when the waters were making their final retreat from off the gradually emerging lands.

This is admittedly only a theory; but it is a theory which accords admirably with the known facts,— a series of facts which are not confined to one or two localities, but which are almost universal over the globe.

FIG. 391. Elephant tusk found during mining operations on the ground of the Tolstoi Mining Company, at Boob Creek, Alaska. (Harrington, U. S. G. S.)

Fossil Elephants. The fossil mammals of the Pleistocene include a great variety of species, and a profusion of individual specimens, while their enormous size is a prominent characteristic.

One of the most typical species is the mammoth, *Elephas primigenius.* Its remains are found in great numbers over nearly all North America, Europe, and Northern Asia. It is identical with the modern Asiatic elephant (*Elephas indicus*), there being only minor and quite insignificant differences between them, chiefly in the pattern of the molar teeth, the transition from the one to the other being "almost imperceptible." (Flower and Lydekker, "Mammals, Living and Extinct," pp. 429, 424.) Specimens of the mammoth have been found which indicate an animal fourteen feet high, or three feet taller than

the great African elephant, Jumbo. (Grabau, "Textbook," Part 2, p. 860.) Other varieties of elephant have received specific names; but there are only unimportant differences which separate them from the mammoth and the modern species.

But an even larger species of elephant found as a fossil, was the *Mastodon americanus*. This animal was some 25 feet in

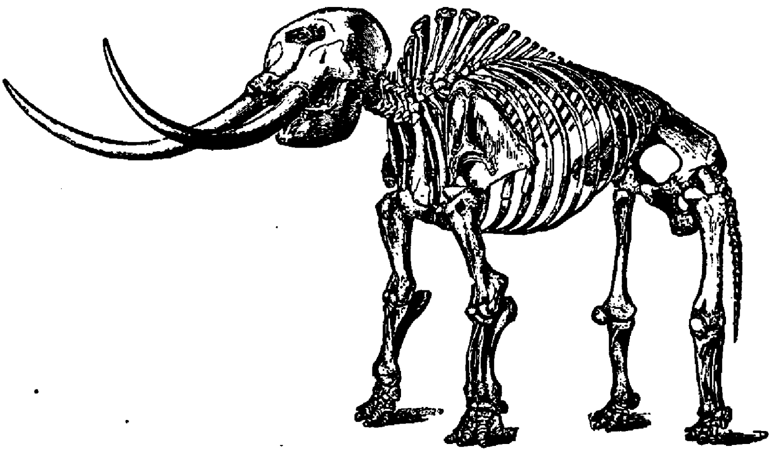


FIG. 392. Skeleton of the American mastodon (*Mastodon americanus*) (× 1/60).

length, including about 7 feet for the tusks. Remains of the mastodon are abundant over most of the northern United States, also in the southern part of the Mississippi Valley, and in Europe. That is, these fossils, with those of the mammoth and other typical Pleistocene mammals, are found far outside of the Drift area proper. The specimens of the mastodon, like those of the mammoth, are often entire, with indications of undigested food. Many individual specimens are also sometimes found in the same locality, as if they had all been buried together.

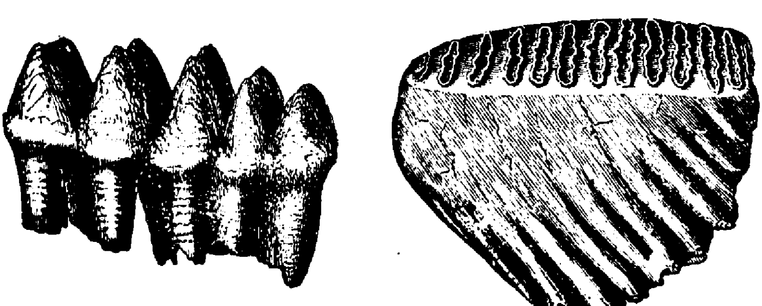


FIG. 393. Teeth of mastodon and elephant.

Remains of the tapir, camel, rhinoceros, saber-toothed tiger (*Smilodon*), gigantic ground sloth (*Megatherium*), and horse, with many other remarkable animals, have been found in various parts of North America.

Foreign. In countries where there is nothing corresponding to the "Drift" proper, it is difficult or impossible to separate the Pleistocene deposits from the Tertiary, and also difficult to separate them from the really modern deposits. But we shall follow the classification as usually given, with this proviso,— that in some localities, the modern deposits are probably inextricably mixed with the Pleistocene.

South America has afforded some amazing specimens of animal life; but most of its bizarre forms, once thought to have been peculiar to that continent, have since been found also in the lower parts of North America, including even parts of the United States.

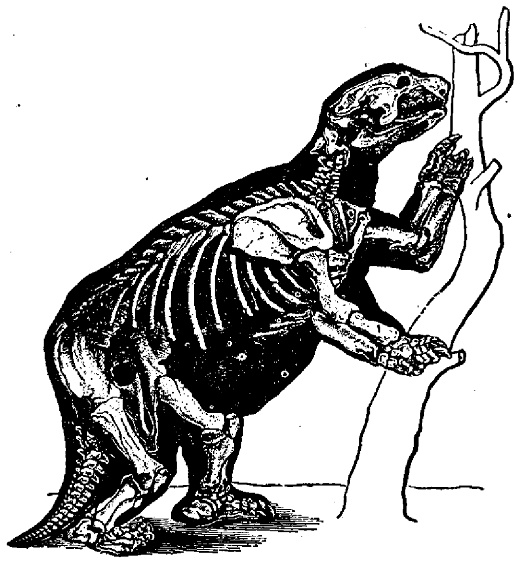


FIG. 394. *Mylodon robustus.* (After d'Orbigny.)

One of the earliest to be discovered of these strange fossil animals from South America, was the *Megatherium*, a slothlike animal larger than the rhinoceros, a skeleton in the British Museum being 18 feet long. "Its massy limbs were more like columns for support than like organs of motion. The femur was three times as thick as an elephant's; the clumsy tibia and fibula were soldered together; the huge tail was like another hind leg, making a tripod to support the heavy carcass when the animal raised itself against a tree and slowly wielded its great arms; and the hands terminating the arms were about a yard long, and ended in long claws." (Dana.) It seems quite impossible to determine whether or not this huge beast was in any way related to the present sloth of South America, except in a general morphological resemblance.

Another edentate from South America, though since found in Mexico and even in the United States, was the *Glyptodon*, an

animal that is always compared with the little modern armadillo. The Glyptodon looked much like a giant turtle, being some 9 feet long. However, it was not a reptile at all, but a true mammal.

"Why such a form as the Glyptodon should have failed to keep his ground is," as Parker remarks, "a great mystery; nature seems to have built him for eternity."

In Europe and Asia, we find several of the species mentioned already from North America, with many additional ones, including the hippopotamus, remains of the latter being found in such northern parts as England.

The broken bones of many of the larger mammals are frequently found jumbled together in the limestone fissures (often called "caves") of France, Belgium, and England, into which they apparently have been washed by the same agency that spread out the "drift" over these northern regions. In a few instances, such bone breccias have been discovered in true caves; and in these, human remains also have been occasionally found. But hitherto it has proved impossible to settle definitely whether the latter represent men who lived contemporary with the mammoth and the hippopotamus in Northwestern Europe, or whether they represent other men, later immigrants into these territories, whose remains were in one way or another, by deliberate interment or by accident, mixed with these antediluvian animals. To the present writer, it seems more probable that no genuine antediluvian human remains have yet been discovered in these cave deposits, or in any other formations from Western Europe.

Australia also has given us some huge creatures, some of the fossil wombats being as large as an ox; while the *Diprotodon*, an animal "closely allied to the living, grass-eating kangaroos" (Nicholson), was as big as a hippopotamus, and possibly somewhat similar in habits.

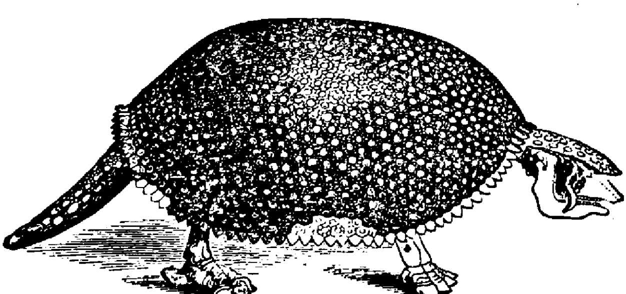


FIG. 395. *Glyptodon clavipes* (× 1/30).

Many of the fossil mammals of Australia were marsupials, as are almost all the larger animals found in that region to-day.

The Life of the Pleistocene

Ambiguity. Within the strict limits of the area embraced by the "Drift," or the so-called "Glacial" deposits, remains of marine invertebrates are not very abundant, occurring only in the few inter-tillite beds of strictly marine origin. These marine invertebrates are much like those of the present day, though they often show an incongruous mixture of arctic and tropical forms in the same beds. Much the same ambiguity attends the plants found in the lignite beds, which are also occasionally found intercalated between the beds of till or other Pleistocene deposits.

On the other hand, as has already been stated, outside the strict limits of the so-called "Glacial" deposits, as in Siberia, Africa, South America, or even in the Southern States of America, no clear line of distinction has been attempted between the Pliocene beds and those of the Pleistocene. Three or four typical deposits from widely separated localities will serve to show the character of these beds, and also to indicate that they do not help very much in the way of smoothing out the transition between the ancient world and the modern one.

Barbados Earths. We will first go to the West Indies. The island of Barbados has a colored clay (*Barbados earth*) which contains an abundance of *Radiolaria*, similar to the radiolarian deposits now forming at the bottom of the deeper parts of the ocean, mainly, however, in the Pacific and the Indian Ocean. On the island are also limestones composed of tests like those comprising the globigerina ooze at the bottom of the Atlantic.

That this represents an elevation of the bottom of the deep water within quite recent time, can hardly be doubted. But that anything like a gradual movement of this nature is now taking place, is entirely without proof. If we associate this elevation with the other geological changes, we can have an explanation of it whenever we arrive at a satisfactory explanation of the others. It is evidently of the same order; and it is manifestly an event of no great antiquity. This fact would seem to imply that the other geological changes of similar character may not be of any great antiquity.

La Brea Formation. About nine miles to the west of Los Angeles, Southern California, are some tar pools (*La Brea formation*), caused by the petroleum of the Hollywood district adjoining seeping up through fissures and preserving almost as

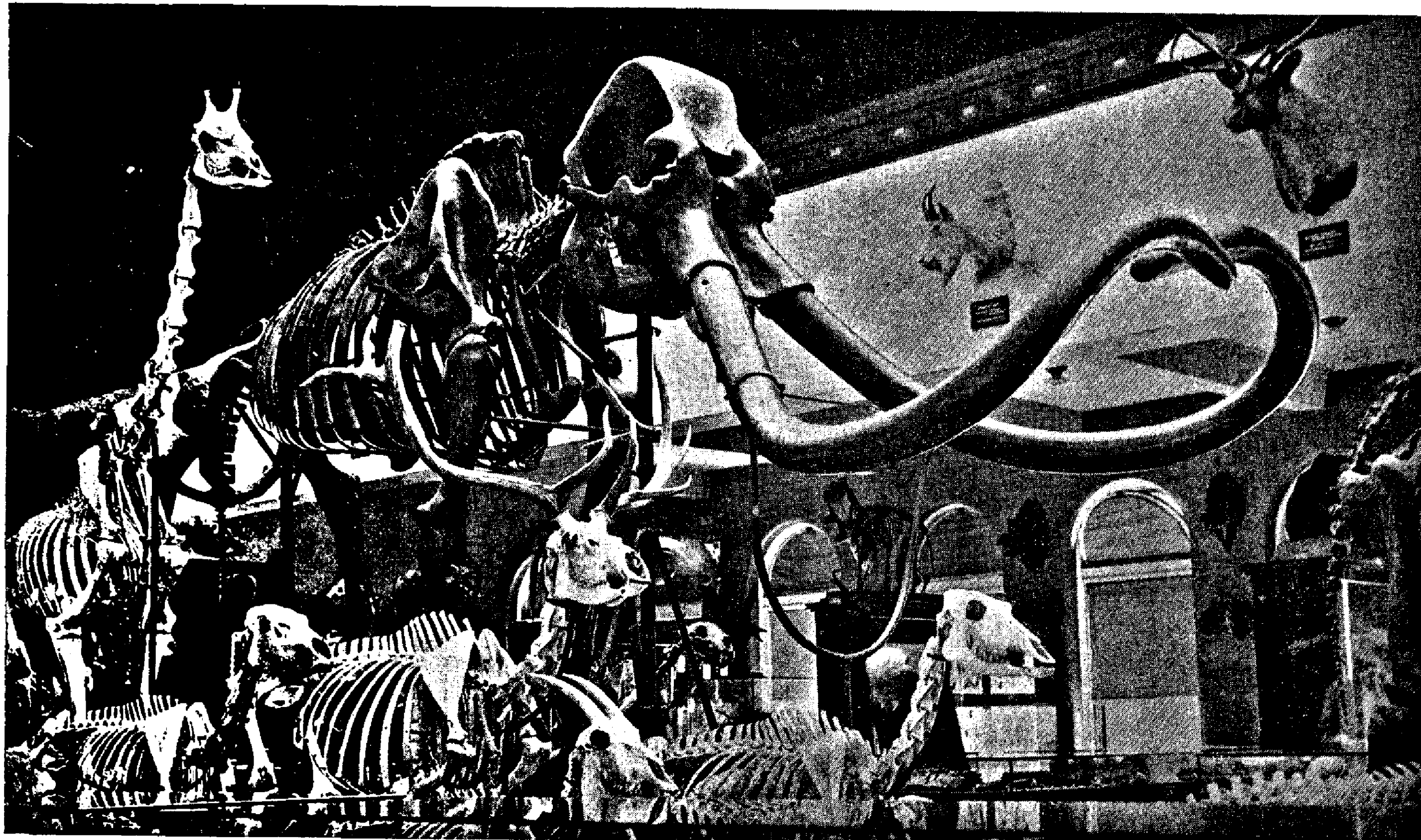


FIG. 396. A view of the skeleton of the imperial elephant on exhibition at the Museum of History, Science, and Art, in Los Angeles. Compare him with the giraffe beside him, or with the big buck in the foreground. The imperial elephant in the Pleistocene epoch ranged west of the Mississippi southward from Nebraska to the City of Mexico.

originally deposited a vast assortment of mammal skeletons. Some modern animals have tumbled into these pits and have become preserved also; but that the deposit is primarily due to the oil's having seeped up and preserved a deposit previously there, is proved by the fact that outside the limits of the effects of the tar, the soil is very calcareous, as if originally crammed full of bones likewise, but these bones subsequently decayed, because the tar did not reach them. Another fact proving that the majority of these animals did not come along and tumble into this tar, is that the bones of all, except a few modern specimens, are broken, mashed, contorted, and mixed in a most heterogeneous mass, such as could never have resulted from the chance trapping and burial of a few stragglers.

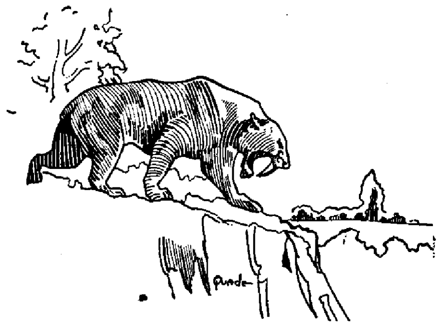


FIG. 397. Saber-tooth tiger (*Machairodus*) from the La Brea (Pleistocene) formation of Los Angeles, California.

Moreover, the animals found here are such as have never lived in this vicinity since the great earth-changes took place. They comprise such animals as the great ground sloth, the saber-tooth tiger, both mammoths and mastodons, a camel, and species of horse and bovines which were extinct when the whites came here. Even a peacock, which is now restricted to the Asiatic tropics, occurs here, with a few other birds, some of which may have been caught in the tar, as they are such as sometimes visit this part of the world. But when the whites came to this region, there were scarcely any animals here, except a few half-starved coyotes and rattlesnakes wandering about among the manzanita and sagebrush.

Obviously we have here a museum made by nature, preserving the remains of a prehistoric fauna which was buried in great quantities, and preserved in an almost perfect state, so far as the materials of the bones themselves are concerned; though, as previously stated, the bones are in most cases broken and thoroughly mixed together. In Pit No. 3 were found the skulls of no less than 268 saber-tooth tigers; while in Pit No. 9 were seventeen elephants (*Elephas imperator*), besides several mastodons, "and a great quantity of bones of the ancient ox, giant sloth, horse, lion, saber-tooth, wolf, and cave bear" (F. S. Daggett), with thousands of bones of smaller animals.

Palermo Breccias. We will next go to the island of Sicily, in the Mediterranean. Here we have a most interesting mass of bones, mostly of the hippopotamus, with a few elephants and other animals, in the bone breccias near Palermo. Twenty tons of these bones were shipped from one pocket or cave-deposit within the first six months after their commercial value was discovered, "and they were so fresh that they were sent to Marseilles to furnish animal charcoal for use in the sugar factories." (Prestwich.) That some extraordinary occurrence caused this astonishing mass of bones, is proved by the fact that "the bones are those of animals of all ages down to the fetus." (Prestwich.) And that something more than a mere earthquake wave, or some other sudden rise of the water, was the cause of this phenomenon, is proved by the known habits of this animal; for it is as much at home in the water as a duck or a beaver. And it manifestly has not lived in this locality within historic times — indeed, could not live there in the present state of climate there prevailing, even though the climate be mild and salubrious.

Siberian "Mummies." We will next go to Northern Siberia, near the mouth of the Lena River, which is very near to the

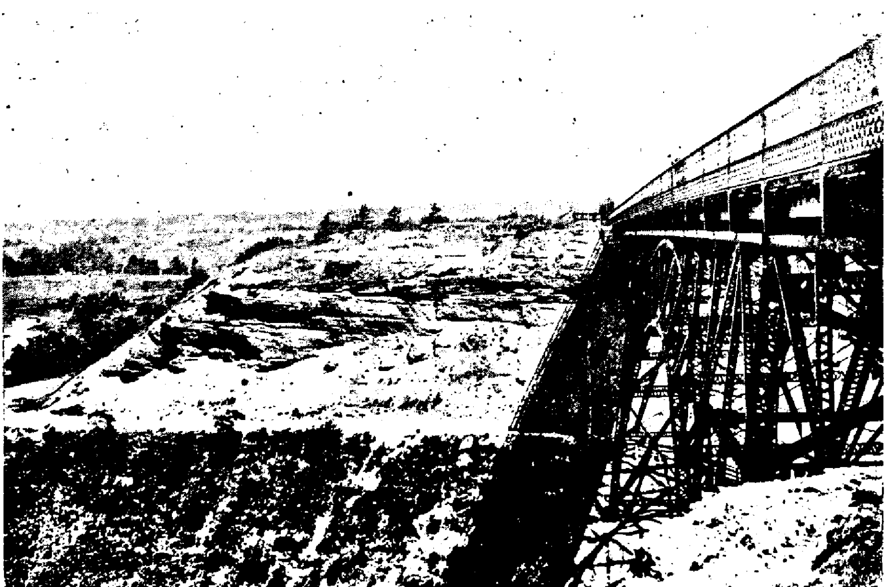


FIG. 398. Section of the great bar of the old "Lake Iroquois" shore line, near Hamilton, Ontario. "Lake Iroquois" is the name given to the much larger lake which once existed over the spot where Lake Ontario is now. (Gilbert, U. S. G. S.)

FIG. 399. Old shore line of Lake Bonneville, on a promontory of the Wasatch Range, Utah. (Gilbert, U. S. G. S.)

coldest spot on the face of the earth; for the cold pole is not by any means at the north geographical pole, but here in Northeastern Siberia. Here mammoths, rhinoceroses, and other animals, seem to fill the frozen soil in certain localities like the bodies of soldiers in a burial trench after a battle. Since the tenth century at least, perhaps for a much longer period, a regular market in the fossil ivory of the mammoth tusks has been carried on both eastward to China and westward to Europe, and "fossil ivory has its price current as well as wheat." (Flower and Lydekker.) Not all the specimens are preserved with the flesh upon them; for in many places, the soil thaws out more or less during the short summer. But occasionally one of these ancient animals comes to light with the flesh in such a state of preservation that the dogs and wolves are greedy to eat the meat, and a party of scientists even had a meal off this ancient meat which has been kept in cold storage so many millenniums.

Bones and tusks of these animals, which are identical with the modern Indian elephant, though larger, are found over practically all of Northern Europe and Northeastern America. And it is at least allowable to think that the same cause (whatever it was) which extinguished so many thousands of them in arctic Siberia may have been the cause of their extermination

over these other regions also; only in Europe and America, the frost has not kept the flesh in such a state of preservation as it has in Siberia.

Much has been said about the coat of hair and wool which this animal possessed. All land mammals, except in cases of degeneration, are provided with a good coat of hair. Doubtless this ancient elephant had use for his coat, which his modern relative in India has not; for he was evidently adapted to the cooler plateaus or mountain sides. But that any amount of fur could make his life safe in a tundra winter may well be doubted. However, it is not so much a case of what amount of cold he could stand, as of *what he could get to eat.* For over a thousand square miles of such country as that in which their fossil mummies are now found, there is scarcely enough vegetation to keep half a dozen of these animals alive for a month, even during the short summer; while they seem to have been entombed by the thousands or the millions. It is clear that at the time these animals lived here, the climate must have been very different from what it is now.

The Sudden Change. And it is equally evident that the change of climate must have been *sudden,* and *as permanent as it was sudden.* As that veteran geologist, James D. Dana, ex-

FIG. 400. Terraces and shore lines of former Lake Bonneville, near Wellsville, Utah. Notice the strong contrast between the topography of the hills above the old shore line and that of the part below, indicating a great difference of age and conditions of erosion. (After Gilbert.)

presses it, the cold "became suddenly extreme, as of a single winter's night, and knew no relenting afterwards." How this sudden change of climate could take place in this part of the earth without affecting the whole earth to a very large and striking degree, is incomprehensible. Here, then, is one fact that we can depend upon, a *radical and extreme change of climate*

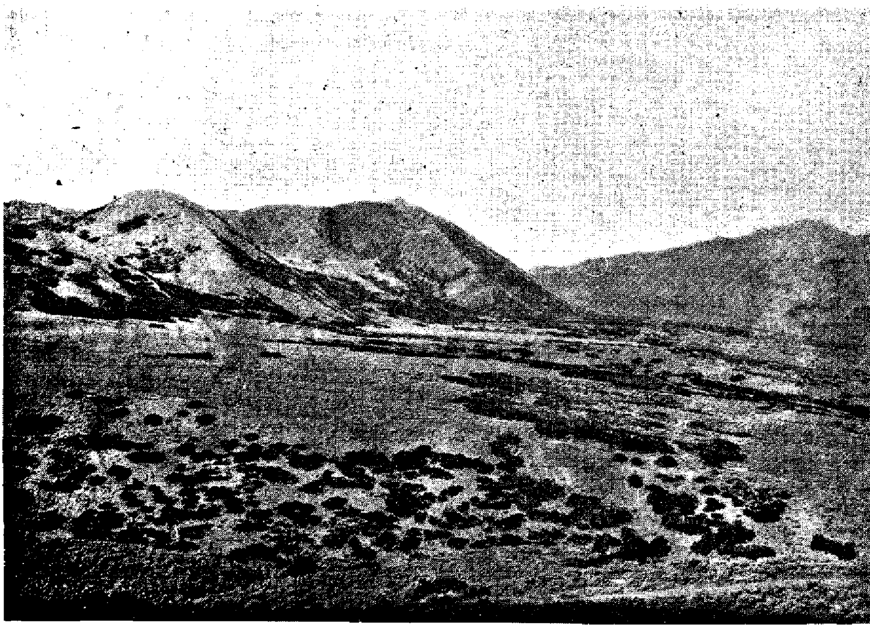


FIG. 401. Old shore line or beach of Lake Bonneville, on the north face of Traverse Range, Utah. (Gilbert, U. S. G. S.)

within the limits of time embraced by animals now alive in our modern world. And this sudden and wide-affecting change of climate is a part of the world-changes with which we have to deal in these Pleistocene deposits.

Relic Lakes. Another line of facts of much importance in this connection, is that regarding what are called *relic seas* and *lakes;* that is, bodies of water now wholly unconnected with the ocean, which contain evidence of having been connected with the ocean in some way, at some time in the not very remote past. Such a relic lake or sea is the Caspian, the waters of which are chemically very like the ocean, so far as their dissolved salts are concerned. And its fauna bears distinct evidence of a former but recent mingling of the ocean with its waters; for it includes salmon, herring, and other ocean fish,

with even porpoises and seals. Lake Baikal, in Siberia, also has herring, salmon, marine sponges, and seals. Lake Onondaga, once a part of Lake Ontario, contains marine squids; while around Lake Champlain are elevated beaches containing very numerous marine shells, with the bones of seals and whales. Still more interesting are some of the inland waters of the tropics, such as Lake Tanganyika, in Central Africa. Here are found jellyfish, marine gastropods, with other marine organisms; but doubt has been thrown upon these facts as indicating

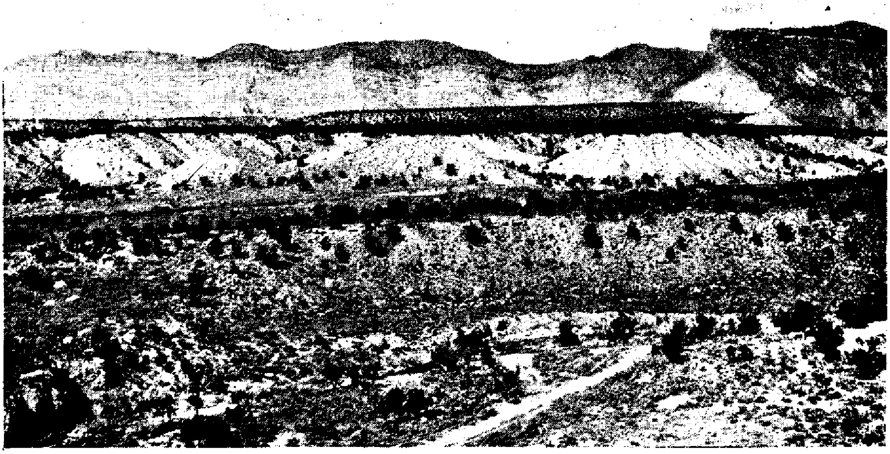


FIG. 402. Gravel-capped terraces in the foreground, and escarpment with coal outcrops in the background. East of Helper, Utah, Castlegate quadrangle. (Clark, U. S. G. S.)

any connection with the ocean, because, forsooth, these relics of marine life resemble more closely *Jurassic forms* than any more modern ones!

"A Zoölogically Impoverished World." "It is clear, therefore, that we are now in an altogether exceptional period of the earth's history. We live in a zoölogically impoverished world, from which all the hugest, the fiercest, and strangest forms have recently disappeared; and it is, no doubt, a much better world for us now they are gone. Yet it is surely a marvelous fact, and one that has hardly been sufficiently dwelt upon, this sudden dying out of so many large Mammalia, not in one place only but over half the land surface of the globe. We can not but believe that there must have been some physical cause for this great change; and it must have been a cause capable of act-

ing almost simultaneously over large portions of the earth's surface, and one which, so far as the Tertiary period at least is concerned, was of an exceptional character."— *A. R. Wallace, "Geographical Distribution of Animals," pp. 149-151.*

This author thinks that he has such a physical cause in the traditional "Glacial Age." But it is easy to see that this "Glacial Age" did not come on *suddenly*, as the evidence re-

FIG. 403. Light-colored Pleistocene sands, in the upper part of the picture, resting upon laminated sands and clays of the lignitic division of the Cretaceous. Cape Fear River, 3½ miles below Elizabethtown, North Carolina. (Fuller, U. S. G. S.)

quires; nor would such a theory explain the sudden and mysterious disappearance of many of the animals which he here speaks of from South America, Central America and Mexico, and Southern Europe. And how much stronger, how irresistible, is the evidence, when we remember that such forms as the dinosaurs and the ammonites, the semitropical floras of the Cretaceous and Carboniferous coal beds, with the trilobites and all their associated companions, can not be separated in time from this common catastrophe, which thus becomes literally and absolutely world-wide in extent!

Other Phenomena. In parts of the south of England, on the Channel Islands, and elsewhere in Europe, the raised beaches are overlaid by what is locally called a "rubble drift" or "head," a peculiar angular breccia formed of local fragments. This in turn is overlaid by the loess deposits; while in some other instances, the loess forms the matrix of the "rubble" or "head." Accordingly, this rubble drift must have been formed after the raised beaches, and it evidently marks a re-submergence of these parts, or a re-transgression of the ocean, which amounts to the same thing. The loess is subsequent; and if formed by water, it must have been deposited during the brief interval of this last submergence. If formed principally by the winds sweeping over the bare and unprotected land surfaces, its formation would then date from the years or centuries immediately following this last submergence. But on either consideration, we have here a true (though merely local) chronology: the raised beaches, the rubble drift, followed by the loess, and the recent. As for the absolute length of time represented by any one of these phenomena or all together, conjectures are of no scientific value.

Part V — Theoretical Geology

CHAPTER XXXVII

A Brief History of Geology

Importance of the Subject. No one can judge fully of the weakness of the present geological theories, or forecast the future development of the science, who does not have clear and somewhat full ideas regarding the history of the science with which we are dealing. In fact, the historical method is a splendid way of studying any question, whether of science, morals, religion, or politics. Most of the other natural sciences, as physics, astronomy, chemistry, and medicine, have each passed through about the same stages of historical development. Beginning as mere speculations, each passed through a period where speculative or *a priori* methods struggled with the rising scientific or inductive methods. Finally these other sciences have now reached the place where scientific methods alone are recognized by the educated world, and speculative fancies are debarred from exercising their baleful influence over the main conceptions of these sciences. At any rate, in all the sciences except geology, facts and theories are kept separate and distinct in all textbooks to be used by students in academies and colleges, so that the student can judge of the value of the theories for himself. In this way, the student has a chance for his intellectual life, his intellectual freedom. But in geology, facts and theories are still inextricably commingled; and in the ordinary college textbook of the science, the most absurd and fantastic speculations are still taught to the students with all the solemnity and pompous importance which might be allowable in speaking of the facts of chemistry or physics.

Thus the history of geology conforms to the same general law of progress seen in the other sciences; only geology has developed much more slowly than some of the other sciences, and has not yet escaped from the period of *a priori* methods and metaphysical speculation.

Among the Greeks and Romans. The abundant fossils found in almost all the Mediterranean countries could not fail to attract the attention of the ancients; but the vain speculations of the Greeks, who made these fossils the occasion for many wild fancies as to how the world was made, have no scientific value. The Romans were somewhat more practical, and Strabo,

Seneca, and the two Plinys wrote on geological subjects with some gleams of common sense. But on the breaking up of the Roman Empire, the world again relapsed into semibarbarism; and for many centuries, a barren system of false education and false methods of thinking blighted the healthy development of the human mind.

The Post-Reformation Period. But with the revival of learning and the Reformation, men awoke as from the hypnotic sleep of ages, and began to inquire for new worlds to explore and new realms of knowledge to study out. The great book of nature also resumed the place in education which it had held among the Hebrews in remote antiquity; and plants, animals, and rocks began to be studied, figured, and described by enthusiastic students, so that in a very short time, a fairly representative literature on all these subjects sprang into existence.

But another strange perversity now seized men's minds; for while the Greeks and the Romans had realized that the fossils were the remains of real plants and animals, the learned men of this period would not admit any such thing.

"With the dawn of the fifteenth century began that long series of disputes about fossils which lasted more than three centuries. The questions under discussion were, whether fossil organisms had taken origin from a *vis plastica,* or from living seeds carried in vapors from the sea, or from any living force in the earth itself; whether they might be regarded as mere illusory sports of nature, or as mineral forms, or if they really were the remains of animals and plants that had once lived and had been brought by the Flood or some other catastrophe into their present position."— *Zittel, "History of Geology and Paleontology," pp. 13, 14.*

However, several people of this time had correct ideas about the fossils. Among them were the famous artist, Leonardo da Vinci, George Bauer (Agricola), Bernard Palissy the inventor, with Steno, and Robert Hooke (1633-1703) of England; who believed the fossils to be the remains of former living things. Robert Hooke was the first to suggest that they might be the means of revealing something of the past condition of the earth; and from the occurrence of huge turtles and ammonites at Portland Isle, he concluded that the "climate of England had once been much warmer." (Zittel.)

The world was now rapidly awaking to the full meaning of these relics of the ancient world; and had not the speculative scholasticism of the Middle Ages still cast its baleful shadow over the science of this time, the secret of the rocky records might even then have been solved. As it was, most investigators felt impressed that the fossils were really relics of the

ancient world that was destroyed by the Flood. Yet, as they were profoundly ignorant of any true *inductive* way of building up a science, they usually made a sorry mess of trying by the subjective method to show *how* the world was *made* and how it was *destroyed;* that is, trying to hit on a postulate from which they could deduce all the facts discovered or discoverable regarding the earth and the rocks. Perhaps in no instance has the puerility of the scholastic method of treating a scientific problem been more manifest than in this and other instances in the history of geology.

Burnet and Whiston are the most notorious of the "diluvialists," as the geologists of that age are called. Their wild fancies deserve to be called travesties alike on the Bible and on true science; and the word "diluvial" has been a term to mock at ever since. John Woodward (1665-1722) was much more rational, and should have credit for helping to prove that the fossils really represent past floras and faunas. He taught that they must have been buried by a universal Flood, the Deluge of the Scriptures; but his books embodied all the scientific knowledge then known, and he restrained his fancy, and endeavored to keep within the bounds of true science.

Happy would it have been for the subsequent history of all the sciences, if the students of the rocks had all been willing patiently to investigate the records, and hold their fancies sternly in leash until they had gathered sufficient facts upon which to found a true induction or generalization. Unfortunately, there lived during this same period other writers on geology who were engaged in spinning fantastic theories about the origin and the history of our world, or as Zittel puts it, "accepted the risks of error, and set about explaining the past and present from the subjective standpoint." And happy would it now be for the world if modern geologists could be said to have entirely outgrown these methods.

Lehmann and Füchsel. J. G. Lehmann was a German miner who in 1761 was appointed professor of chemistry and director of the Imperial Museum at St. Petersburg, by the czarina Catherine, of Russia, and was one of the real founders of the science of geology. He divided the rocks of the earth into three great divisions, the *Primitive,* the *Secondary* (containing the fossils), and the *Alluvial* or superficial deposits, which last he held to be due to local floods and the Deluge of Noah. His work was chiefly confined to those rocks of Thuringia since classed as Permian.

Dr. Füchsel (1722-1773) studied in great detail those rocks of the same district now known as Triassic. He was the first to use the word "stratum," and also the term "formation." The latter he used in pretty much the same sense in which it is used to-day, as including all the rocks which had been made at a certain epoch in the history of the earth. He distinguished nine of these "formations" from the oldest to the Middle Triassic. His work gave to the word "formation" a time-value; and as this idea was afterwards taken up by Werner and his pupils, it had a very profound influence over the subsequent history of the science in Germany and the rest of the world. We see in this teaching the germ of those chronological onion coats which have since been so notorious; though Werner made this term "formation" to be based strictly on lithic or mineral composition.

Both Lehmann or Füchsel, and particularly the former, were following true empirical or scientific methods. Their work was especially of value to later students of the rocks in being exhaustive descriptions of particular localities,— descriptions that have seldom been equaled since. However, in so far as they indulged in speculations about *time*, and laid off the strata in groups or "formations" representing successive ages, they were tacitly making these small localities,— mere spots on the globe,— the standard by which to judge all the rest of the world, thus leaving safe inductive methods far behind. This monstrous assumption that, because the rocks occur in a certain order in a particular locality, therefore they must be found occurring in this same order *all over the globe*, has ever been the stumbling-block of geological science; for it involves the palpable absurdity that different kinds of sediment could not be forming contemporaneously in localities distant from one another, or that distinctly different kinds of life did not coëxist in separated localities in the long ago. In other words, this idea, from its very first inception, implied that each of these "formations" encircled the globe like an onion coat. Thus far, the rocks were being set off in "ages" chiefly on the grounds of their mechanical and mineral make-up. Werner continued the idea, but founded it strictly on lithologic characters. To make the fossils the real test of a "formation" was an invention of a much later date.

Count Buffon. The French naturalist Buffon (1707-1788) seems to have been the real father of the evolutionary development of life as read from the rocks, or the geological succession of life, much as we now understand it. He is said to have

remarked about the previous writers on geology that they must feel much like the ancient Roman augurs, who could not meet in private without laughing in one another's faces at the fooleries which they perpetrated on the confiding public. He unhesitatingly combated the idea of a universal Deluge, and with the little smattering of geological facts at his command, undertook to construct a detailed history of *"the beginning, the past, and the future of our planet."* (Zittel.) His reputation obtained in other lines of scientific knowledge served to invest with a quasi scientific character this tissue of unscientific speculations, and to fasten on the world for another hundred years the habit of dealing with geology as the scholastics of the Middle Ages dealt with all their "sciences," from the subjective point of view.

From this time down, it would seem that practically all writers on geology have never had a doubt that somehow there has been a succession and progression in the types of life which have existed on the globe, and that it is the principal business of geology to work out and illustrate this wonderful fact of organic development. All subsequent theories of evolution seem to be but variations and amplifications of this remarkable idea which Buffon extracted from the scanty data available a hundred and seventy years ago. Even the seven *"days"* of creation, taught by Thomas Chalmers, Hugh Miller, and other religious geologists of the early nineteenth century, who tried to quiet the scruples of the church by their *"day-period theory"* of creation, seem to have come bodily from Buffon's seven "epochs"; and it has taken many a long year to show the unscientific character of this cosmological speculation, as we now know this notion to be.

The "Heroic Age." From 1790 to 1820 followed what Zittel calls the "Heroic Age" of geology. It was characterized by a determination to discard speculation, and by an honest endeavor to build up a true science of actual fact and truth. Many keen-eyed, scholarly men of this period, men who had command of all the geological facts then obtainable, held to a catastrophic interpretation of geology. Others held very divergent views; but while the study of minerals was regarded as a true science, geology (or *geognosy*, as it was then called) was not considered as of sufficient importance or dignity to warrant the classing of it with the other natural sciences. Geologists were regarded as mere collectors of curiosities, or as persons who liked to indulge in fanciful dreams about how the world was made. Even Comte, when he issued his classification of the

sciences in 1820, denied a place to geology altogether, saying that it was not a distinct science at all, but only a field for the application of the various sciences. In fact, the nineteenth century was well advanced before geology had secured a well-recognized place among the other natural sciences. The establishment of geological surveys by the British government and by other governments, marks the beginning of the rise of geology as a well-recognized science.

Werner and His Theories. But we must go back to the days of A. G. Werner (1749-1817), who long held the position of professor of mineralogy at Freiberg, Germany. He was the great original "Neptunist"; for he taught that all the rocks of the earth's crust had originated as mechanical or chemical *precipitates* from aqueous solutions which in the beginning had enveloped the whole globe. Volcanic products, he claimed, represented rock material originally formed in this way, but subsequently melted and ejected. Thus he taught that all volcanic rocks are *later* than the sedimentary, and that volcanoes are caused by the burning of coal deposits beneath the ground.

He was a clever and enthusiastic teacher, and undoubtedly knew as much about mineralogy as any other man of his time. For several decades, his influence over both mineralogy and geology was practically unbounded. "From all parts of Europe students came, and when they returned to their own countries they spread the teachings of geognosy and mineralogy as Werner had taught it to them." (Zittel.)

Following the theories of Füchsel and of a certain Swedish scientist named Bergman, Werner distinguished five "suites" or series of rocks, each characteristic of an age or epoch in the earth's history; and he taught that each of these "suites" enveloped the globe, one outside another, like the coats of an onion, each one originally being universal around the globe.

In all this speculation, he was, of course, wandering far from true inductive methods. Quite likely he never heard of Bacon's *Novum Organum* or of Newton's *Principia.* And in view of the rank absurdities which he taught, and of the surprising vogue which these absurdities attained throughout the civilized world, the remarks of Sir Archibald Geikie seem none too severe:

"But never in the history of science did a stranger hallucination arise than that of Werner and his school, when they supposed themselves to discard theory and build on a foundation of accurately ascertained fact. Never was a system devised in which theory was more rampant; theory, too, unsupported by observation, and, as we now know, utterly erroneous. From

beginning to end of Werner's method and its applications, assumptions were made for which there was no ground, and these assumptions were treated as demonstrable facts. The very point to be proved was taken for granted; and the geognosts, who boasted of their avoidance of speculation,

FIG. 404. A. G. Werner (1749-1817), the originator or promulgator of the "onion-coat" theory.

were in reality among the most hopelessly speculative of all the generations that had tried to solve the problem of the theory of the earth."—*"Founders of Geology," p. 112.*

The dogmatic confidence of those who for so many years controlled the teaching of geology and mineralogy in all the countries of Europe, is well illustrated by the following remark of the same author:

"The Wernerians were as certain of the origin and sequence of the rocks as if they had been present at the formation of the earth's crust."

From a study of the paleogeographic maps found in so many modern textbooks, as well as from the detailed descriptions which go along with them, we must conclude that the modern writers are not very far behind the followers of Werner in their dogmatic certainty about the origin and sequence of the strata.

In speaking of Werner's five successive "suites" or onion coats in which he enveloped his embryo world, Zittel says: "Unfortunately, Werner's field observations were limited to a small district, the Erz Mountains and the neighboring parts of Saxony and Bohemia. And his chronological scheme of formations was founded upon the mode of occurrence of the rocks within these narrow confines."—*"History," p. 59.*

FIG. 405. Alexander von Humboldt (1769-1859. He was a great traveler, and did much to promote an interest in scientific observation. Unfortunately, in geology he followed blindly the theories of A. G. Werner, of "onion-coat" fame.

The Modern Onion-Coat Theory. Yet it is precisely such a charge as this that we must bring against the modern phase of the doctrine of successive geological ages based on the succession-of-life idea. Werner, from observations "limited to a small district," constructed his scheme of exact chronological sequence based upon the mineral or mechanical character of his "suites." And hundreds of enthusiastic disciples in England and Scotland, France and Germany, long declared that whereever they went, they found the rocks in the exact order taught by the great prophet of Freiberg. Even so great a scientist as Humboldt, in his trips through Central and South America, always reported finding rocks in the order of Werner's chronological arrangement.

But we now know that in other parts of the world, the rocks do not occur as Werner decreed. Even in the parts examined by his followers, it has developed that they made many and grievous blunders of observation, due to the hypnotic suggestion of their supposedly infallible theory. Besides, we know that in our modern world, one kind of mineral or rock may be forming

in one locality, while a totally different kind of deposit may be forming some miles away *at the very same time;* and we have no scientific ground for assuming that there ever was a time since life appeared on the globe, when this principle would not hold good. Such cosmological speculations do not promote inductive science. But in the very same fashion, the idea of a time-value was, as we shall see, transferred from the mechanical and mineral character of the rocks to their fossil contents; and again, from observations limited, like Werner's, to a few spots of England and France, William Smith and Cuvier conceived the idea that the *fossils always occurred in a certain definite order;* that only certain fossils had lived at a certain time; that, for example, while trilobites were living or being buried in one locality, other types, such as dinosaurs, or nummulites, or mammals, were *not* living or being buried in another locality, though in any system of clear thinking, this latter notion is just as irrational, just as unscientific, as that of Werner.

In short, this new system of identifying the rocks by their fossils still retained the essential absurdity of the onion-coat theory, namely, the *universality of one kind of deposit.* It merely restated this theory in terms of the fossils, instead of in terms of mineralogy and mechanical texture. It involved all the arbitrary assumptions, all the incredible fictions about unnatural past conditions, which characterized the theory of Werner which it professed to displace. And modern geology has never got completely rid of the characteristic absurdity of this whole system of cosmology; namely, the universality, in the long ago, of one *limited* assemblage of life-forms. Hence, even Herbert Spencer, seeing this, declares that "though the onion-coat hypothesis is dead, its spirit is traceable under a transcendental form even in the conclusions of its antagonists." ("Illustrations of Universal Progress," p. 343.)

The two cases are exactly parallel; only it has taken over a century to convince us that the fossils do not follow the prearranged order of Smith and Cuvier any better than the rocks and minerals follow the scheme of Werner. If most modern geologists still think that the fossils in general agree with the standard order, we must remember how many sharp-eyed observers said the very same thing for decades about Werner's scheme. But both systems exhibit the same reckless disregard of the basic principles that must control all scientific research to make it of permanent value, and both have now been found to be equally at variance with modern discoveries.

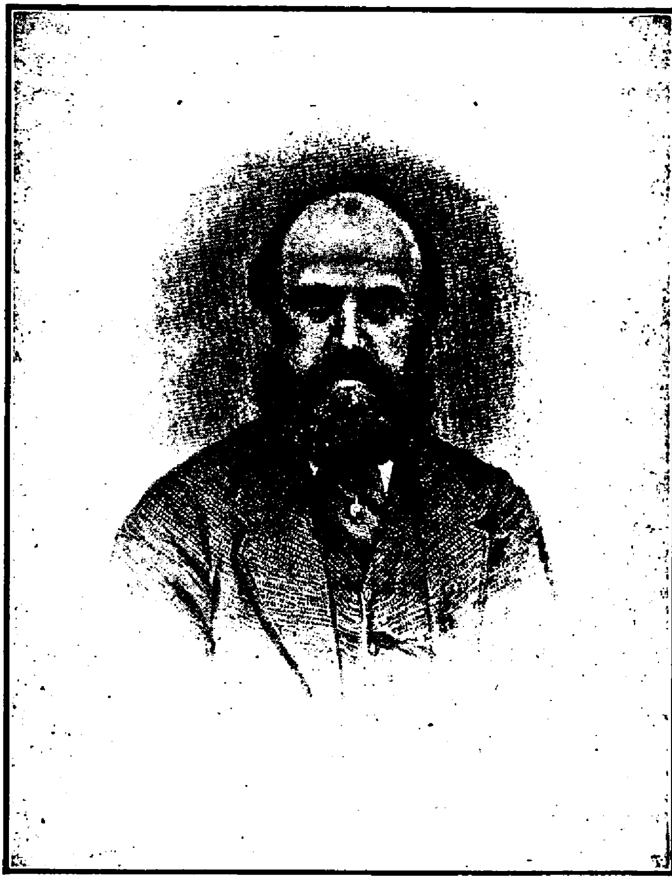


FIG. 406. William Smith (1769-1839), often called "Strata" Smith, also the father of English geology.

William Smith. It was William Smith, an ignorant English land surveyor, who first suggested the idea of fixing the relative ages of strata by their fossil contents. He wrote no books, and it is a little difficult to tell just what he did teach; but his theory seems to have been only a crude rule-of-thumb by which the various outcropping rocks in distant localities throughout England could be identified by their fossils, and thus be proved to be continuous underground between these scattered outcrops. His ideas were handed around privately among some clergymen and other enthusiastic fossil collectors in England, and soon became quite popular. Ultimately he and his disciples came to the conclusion that one and the same succession of strata extended across England from the south coast to the east, these rocks be-

ing now classed as subdivisions of the Jurassic and Cretaceous systems; that certain fossils always "reappear in the same bed in the different localities; and that each fossil species belongs to a definite horizon of rocks." (Zittel, "History," p. 110.)

The Mistake in Smith's Methods. The fault with Smith's theory is the fault common to all crude guesses based on wholly insufficient data; for even granting the accuracy of his observations for the rocks which he had seen, it is evident that his theory has all the infirmities of Werner's scheme, of which Whewell says that "he promulgated, as respecting the world, a scheme collected from a province, and even too hastily gathered from that narrow field." ("History of the Inductive Sciences," Vol. 2, p. 521.)

Not only so, but each of these theories has the additional flaw of being but another attempt at a *cosmogony*. Hasty generalizations and crude guesses are bad enough at any time and in any department of knowledge. But the history of human thought shows that in no other department have otherwise sensible men shown such puerile folly as when they have tried to describe in a circumstantial way just *how the world was made*. One of the reasons for this result is that the construction of a scheme of world-building is the very quintessence of subjective speculation; and the development and after history of these theories of Werner and Smith serve clearly to illustrate what a deadly taint this subjective method imparts to all the subsequent studies with which it is even remotely connected.

Cuvier and His Work. Baron Cuvier (1769-1832) is the next to be mentioned in this historical sketch, as this otherwise great scientist must be considered in an especial sense the father of the modern system of cosmological geology, and thus, we might almost say, the father of modern biological evolution; for however limited in their outlook the provincial minds of Werner and Smith may have been in their general view of the subject, and in their comprehension of the connection between their scheme of successive kinds of rock and the general doctrine of a complete world history, Cuvier was certainly not thus mentally limited. In his broader intellect, these successive ages of Werner (he seems never to have heard of his obscure contemporary, William Smith) suggested the possibility of constructing a similar scheme of the history of creation covering the various kinds of plants and animals. "How glorious," he wrote in his "Preliminary Discourse," "it would be if we could arrange the organized product of the universe in their chrono-

FIG. 407. Georges Cuvier (1769-1832), founder of the old doctrine of "catastrophism," which was rather a doctrine of creation on the installment plan.

logical order, as we can already do with the more important mineral substances."

Accordingly, he undertook to arrange the fossil plants and animals in successive ages, just as Werner had done with the minerals; and under the influence of his great name, the educated world granted this theory a cheerful acceptance which Smith's similar idea might never have attained alone. By the end of the second decade of the nineteenth century, this idea of successive ages of various types of life had largely displaced the former system of Werner. But not until well on toward the middle of the nineteenth century were the results of such a fantastic scheme regarded very seriously by the students in

other lines of science. Charles Lyell adopted this system and incorporated it into his scheme of uniformity; and when his works became popular, they carried with them into universal acceptance this system of tabulating the rocks off in successive ages according to the fossils which they may happen to contain.

The Reverse of the Baconian Method. It will not be necessary to give in detail the peculiar manner in which the geological outline of successive ages was gradually pieced together into a complete whole from the strata found in England, Germany, Russia, and the State of New York.

We should note here that this whole chain of life as represented by the fossils was practically completed according to the methods of Cuvier, before any serious attempt was made to study the rocks *on top of the ground,* the last to be deposited and the most closely connected with our modern world. *It was a mere phantom world with which these early geologists felt that they were dealing, a sort of fairy world of the long ago, with no connection whatever with the world in which we now live.* For nearly half a century, geologists denied that the fossil world had anything to do with the world of plants and animals which we now see about us; and only long after the geological history of the many successive ages had been mapped out in this stereotyped form, was any effort made to find out how this strange record of the past joins on to the modern world.

But this was completely reversing the true Baconian method, *for it left over to the last the most important data of all, those facts which held the key to all the rest,* namely, the rocks containing human remains and those of other living species of plants and animals; with the result that we have for more than half a century been laboring under a "glacial nightmare," and these deposits on the very top of the ground "still remain in many respects the despair of geology." (Howorth.) Cuvier, indeed, denied till the last that there was any organic connection between the fossil world and the modern one, declaring that absolutely *all* the fossils are *extinct* species.

Subsequent History. Contemporaneously with this work of Smith and Cuvier, Lamarck (1744-1829) was formulating a biological theory of how species become transformed into other new species through the direct influence of their environment, and through the transmission to their offspring of the changed habits and structures acquired by the use and disuse of particular organs,— a theory which was ridiculed by his contemporaries, and which received consideration only when supplemented

FIG. 408. J. B. de Lamarck (1744-1829). The founder of the theory of the progressive and imperceptible transformation of one species into another by a natural process of evolution. He thought this change was brought about chiefly by the transmission in heredity of the effects of use and disuse. We now know that this latter is a pseudo-scientific notion, not supported by fact.

by that of natural selection a half century later under the teaching of Darwin.

The Rise of Uniformitarianism. The great outstanding figure in geology during the middle nineteenth century was Sir Charles Lyell (1797-1875). As we have already intimated, he adopted the system of Smith and Cuvier of identifying the rocks by their fossil contents. This he supplemented with his own characteristic theory of *uniformity,* by which he undertook to explain all the changes recorded in the rocks in terms of the present-day action of the elements. Such a scheme could logically end only in a system of organic evolution; for as Huxley has remarked, not only was Lyell the chief agent in smoothing the road for Darwin, so far as he, Huxley, was concerned, but "consistent uniformitarianism postulates evolution as much in the organic as in the inorganic world." ("Life and Letters," Vol. 1, p. 168.)

FIG. 409. Sir Charles Lyell (1797-1875).

The Evolution Doctrine. We have not here the space to describe in detail the respective parts contributed to this general idea of organic development by such men as Agassiz, Darwin, Wallace, Weismann, and many others. With the general outline before them of the successive types of plants and animals occurring in what was regarded as a true historical order, there is not much wonder that the scientists of the latter part of the

FIG. 410. Charles Darwin (1809-1882).

nineteenth century believed that Darwin's theory had cleared away the last difficulty, and that they had a complete scientific account of how the various modern species of organisms had developed from cruder and less organized originals. As the result of this combination of geology and biology, the world for several decades thought that the great problem of the origin of life and of living things had been completely solved by science.

However, in the further attempt to verify all the details of this extraordinary theory of how the organic world has evolved, doubt has been thrown upon one after another of those great leading doctrines on which the evolution theory has been built up. The process of natural selection was seen to be incapable of originating anything. The doctrine of the transmission of

acquired characters had to be discarded through the failure to find a single example of such transmission which would stand scientific investigation. Finally, the investigations inspired by Mendel's discoveries have put a serious question into the very basis of the theory regarding the supposed unlimited tendency to vary on the part of plants and animals. As the consequence of all these biological investigations, such men as Dr. William Bateson are now declaring openly that we really do not know anything about the way in which new species of organisms can originate by either artificial or natural processes. It thus appears that all the biological phases of the theory have been about worked out; and that nothing is left but the original skeleton on which the theory was hung, that is, the geological outline of alleged successive forms of life, according to the scheme of Smith and Cuvier.

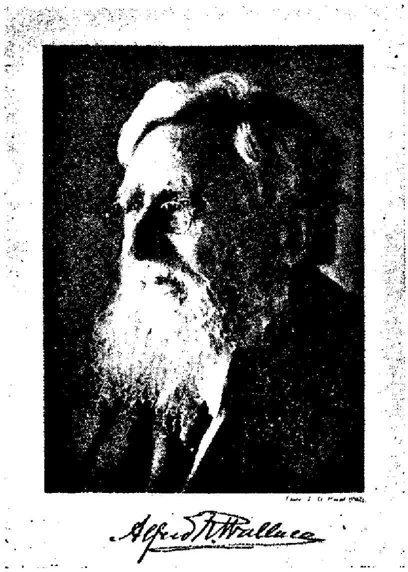


FIG. 411. Alfred Russel Wallace (1823-1913).

The final chapter in the history of the refutation of the evolution doctrine was entered upon about the beginning of the present century, when it was discovered that the successive geological ages were not scientifically established, but were at best merely an assumption; while many geological facts have come to light which show that the assumption of these successive biological ages must be a serious blunder after all. Not only so, but the doctrine of *uniformity* as taught by Lyell has also fallen into disrepute; for we now know that there seems to be no modern action going on around our coasts to confirm Lyell's theory that such a rise and fall of the lands is now taking place. Hence we have absolutely nothing now occurring by which to interpret the great exchanges of land and water that are recorded in the fossiliferous strata.

Thus with biology acknowledging that it has come up to the end of its blind alley, and with its supposed geological outline already discredited and proved to be without scientific foundation, the scientific situation is to-day very different from

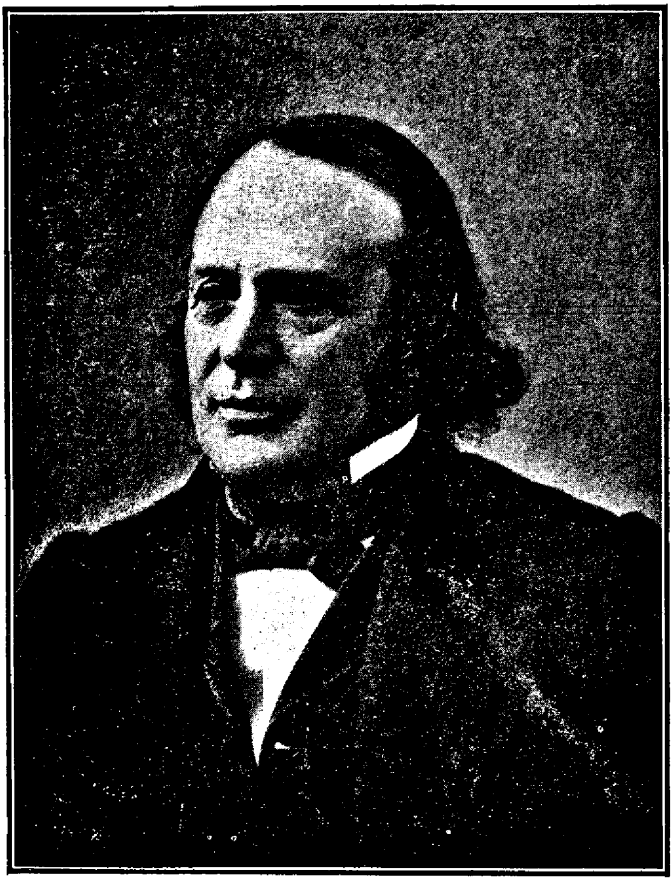


FIG. 412. Louis Agassiz (1807-1873). He might well be called the father of natural science in America.

that which prevailed a half century ago. Evidently it is only a question of time until the world will see the complete collapse of that doctrine which loomed so large in the eyes of scientists during the latter part of the nineteenth and the early part of the twentieth century. For nearly a century, science has been trying to explain the origin of things. It has had a free hand, and has done its best. But it has failed to give us a plausible explanation of the origin of things which will stand scientific scrutiny.

The Lesson from It All. What then may we give as the chief lesson to be learned from the record of this hundred-year search for a scientific explanation of the origin of man and

of the organic world in terms of the processes now going on? One of the most obvious lessons is that natural science properly has nothing to do with such speculations as to the origin of things. The working out of the details of *how* creation was brought about is wholly *beyond the sphere of natural science;* and in theorizing along these lines, the speculative spirit always comes in to vitiate the accuracy of our conclusions and debauch the true spirit of scientific research.

A hundred years ago every writer on geology was confident that he knew all about the general process of how the world was made. Wholly immune to doubt, and unconscious of the

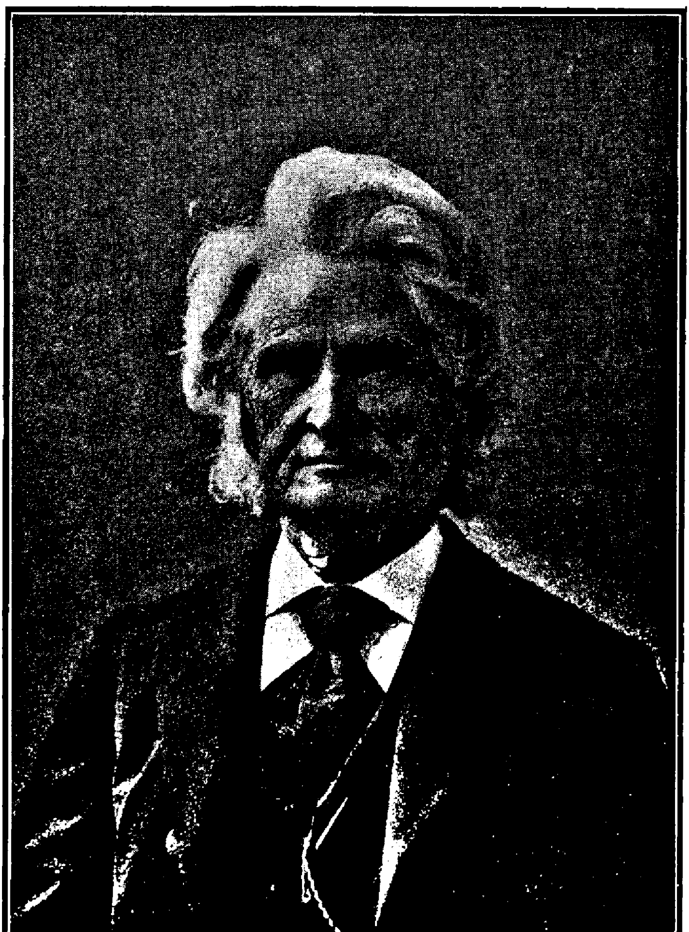


FIG. 413. James D. Dana (1813-1895).

FIG. 414. August Weismann (1834-1914). His great and lasting contribution to science was in showing that acquired characters are not transmitted to offspring.

futility of such a course, such men as Cuvier and Lamarck, Lyell and Agassiz, thought they had discovered what they had only invented, and easily mistook their subjective inventions for real objective discoveries. And while it has taken nearly a century of active scientific investigation in all the departments of natural science to prove that the ideas of these men were wrong and were wholly unscientific, yet the results have been well worth all that they have cost.

We now see that natural science can not legitimately have anything to do with attempting to explain the process of creation — at least, it is useless to attempt to explain the origin of things in terms of the natural processes now going on in our modern world. The net results of all modern scientific investigation seem to be that the plants and animals now alive could never have originated by any such method of gradual development as has been pictured to us in the name of natural science. Certain it is that modern biology, and geology also, for that matter, have simply developed a complete *negative demonstration against* the easy assumptions of the earlier scientists that plants and animals probably originated by a gradual progression from the lower to the higher types by processes similar to those which are now going on.

A hundred years ago — nay, fifty years ago — this assumption of being able to explain creation in terms of present everyday processes, did not seem so untrue, so unscientific, as it now appears; for we did not then have the details of the scientific evidence, both biological and geological, with which to refute such an idea. But in this third decade of the twentieth century, in the light of the marvelous progress which science has been making, this profound mystery regarding the origin of things, this great lesson concerning our creation and our destiny, is brought home to us by all that we know in every department of natural science; and with weary, reluctant sadness does human science confess that about the origin of life, or about the origin of the whole world of organic forms, as well as about the origin of the very globe itself, she knows absolutely nothing.

The Demonstration of Creation. It is necessary to make this latter point clear; for it is the very acme of the results of modern science, the outcome of all our modern investigations. Science is based upon what we really know about the natural world. But when all our studies serve only to impress upon us more deeply the conviction that we do not know anything and can never hope to know anything in a scientific way of how the world was made, or of how the various types of life came into existence, the conclusion is inevitable that creation must have been something *different,* essentially and *radically different,* from anything now going on in our world.

The central idea of the evolution doctrine is *uniformity;* that is, it teaches that what is now going on is identical with or similar to what has always been going on; that the present is the correct measure of *all* the past; and that the present operations of nature are as much a part of creation as anything

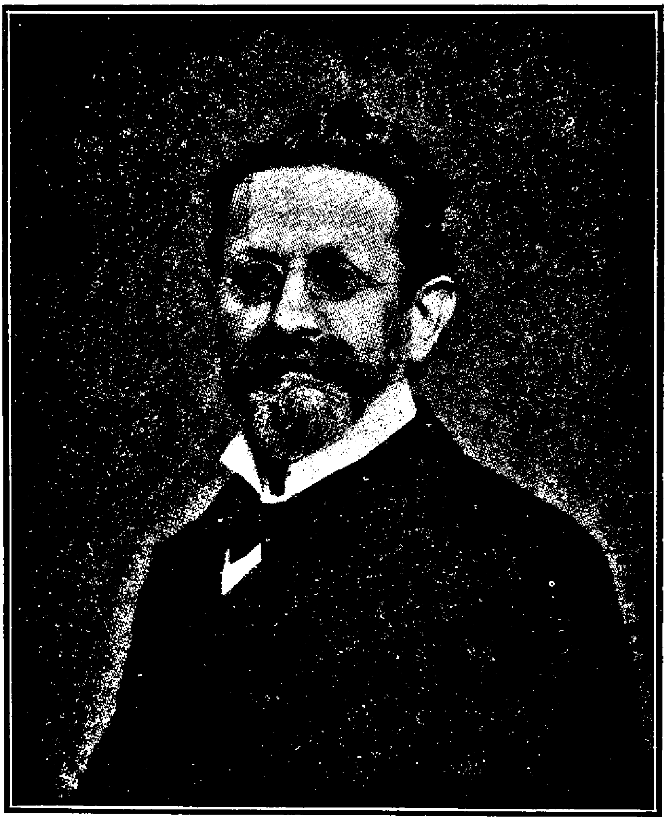


FIG. 415. Karl Von Zittel (1839-1904), late professor of geology and paleontology in the University of Munich. One of the foremost of paleontologists.

that ever took place at any time in the long ago. But the net results of modern science are against all this. They assure us unmistakably that there must have been a real, direct creation at the beginning, essentially different from any of the processes by which the present order of things is now sustained and perpetuated. The record of creation as given in the opening words of our Bibles is now being vindicated by modern science in a way as surprising as it is conclusive; for this vindication is being brought about by those very means which men have supposed would discredit this doctrine of creation forever. "In the beginning God created the heaven and the earth."

In that one word, *created,* we have crossed the boundary of strict inductive science, and have entered the domain of philosophy and theology. But if now the customs of modern scien-

tific inquiry ask us to bid adieu to that guide, demonstrable science, which has conducted us thus far, and which has pointed us to the portals of the temple, we can not ignore the fact that our guide declares emphatically that she has examined and proved worthless and dangerous every other path save that which leads in the direction of the temple of the great Creator. She may not be allowed to accompany us across the deep, dark abyss which separates the field of knowledge from the temple of faith; but she can at least assure us of the real existence of that other and better land which lies behind the portals to which she is now pointing us. Reluctantly she declares that she can not go with us; but she points onward and upward.

Yet, as we bid good-by to our guide, we must not for a moment think that we are treading on ground any less firm than that upon which we have walked before. Can we be sure of nothing beyond what we can see, and feel, and measure, and the conclusions which we can build by syllogisms from these things? Rather must we acknowledge that there are axiomatic truths of philosophy and religion that we can not escape from or ignore. *Creation is one of these axiomatic truths;* and though natural science must not be expected to do more than point the inquirer to this inner sanctuary of truth, yet she has in this reconstructive system of geology given us a demonstration which the world can never again ignore, of the fact that the plants and animals on our globe *were not produced by any combination of the processes now going on around us.* The other possible alternative interpretations have been tried and found wanting. The Bible record of a universal Deluge is so wonderfully confirmed by these contemporary documents in stone, that inexorable logic compels us to go back of all this and face the great problem of creation itself. And although natural science can not be expected to tell us the details of *how* creation really was accomplished, yet in demonstrating that things could not have originated by means of the processes now going on, she has effectually *demonstrated the truth of creation in the only possible way.* And this demonstration comes to us in this third decade of the twentieth century as the most sublime and august thought which can occupy the human mind. The many mistakes and blunders which have marked the constant progress of natural science as she has toiled along the path leading in this direction, can now well be ignored and forgotten, since we have at last arrived at that position where, with bowed head and hushed heart, we feel that we are being ushered into the very presence of our Creator.

The Unique Position of Geology. Alone among the sciences, geology conducts us back into the past and reads for us the history of our earth. The record of this history was long misread, and was supposed to indicate that creation has slowly taken place during the lapse of uncounted ages. Admonished by past mistakes, and holding to the stern logic of demonstrable science, while bringing into the field of vision all the data made available by modern discovery, geology is now beginning to read from these epitaphs in stone the sad story of how that ancient world, "being overflowed with water, perished."

For our age, skeptical above all others regarding the wonder-working power of God, these unanswerable proofs from the contemporary documents of nature, recording the death and burial of that beautiful world, have been reserved as final and unanswerable arguments. But not alone as an appeal to our fear and dread. Rather do they come to us with the sweet assurance that some day the bright, happy conditions of Edenic life will be restored to our sin-blasted planet, and God's redeemed people will shine forth in the restored image of divine beauty. "And there shall be no more death, neither sorrow, nor crying, neither shall there be any more pain: for the former things are passed away."

CHAPTER XXXVIII

Do the Fossils Occur in a Chronological Order?

The Alleged "Invariable" Order of the Fossils. We must now group together some of the more important facts which have been discovered in recent years regarding the order in which the fossils are said to occur. That is, we must consider whether or not they occur in a real world historical or chronological order. For nearly a hundred years, it has been assumed and confidently asserted by writers on geology that the fossils always occur in a very definite order of sequence, this order being a true historical order, thus showing the real order in which life has occurred on the globe.

It has been asserted that the fossils always occur in the same relative order in one country as in another, and that this order shows the real history of the way in which life in all of its diversified forms has developed. It is stated that the order shown by the fossils in one country is never contradicted in another country; and as the lower ones were evidently laid down first, we have here a true historical sequence, which, by being enlarged and considered from the world as a whole, shows the history of life on the globe.

This is all there really is behind the sage remark often given by a teacher or writer on geology to the young student: "It has been discovered that certain fossils occur only in the oldest strata," etc. But *when* was this discovered? And how was it known (independently) that the rocks in which such and such fossils were found are *really the oldest?* When or where was it discovered that the rocks always occur in an invariable order of sequence? We have already considered the history of the science in a brief way: does this history show *when* these wonderful discoveries were made?

It would seem that every natural science worthy of the name ought to be susceptible of the closest dissection and scrutiny *logically;* and we ought to be able to-day to *start* from the raw material facts and build the foundations of the science without any regard whatever to its history. In physics, or chemistry, or astronomy, it would never do to say to the beginner that the basic facts and principles of the science were worked out long ago by the founders of the science, but that these foundation principles are too abstruse and recondite to be explained to be-

ginners. In all these other sciences, we try to start the young student off with a full set of *facts,* instead of with some one's *ipse dixit.* Why not do the same in geology?

How Shall We Begin? The fathers of our science always present us with the geological "time-table" ready-made. If we are to *start from the raw facts,* instead of beginning with the

FIG. 416. Dakota and Morrison strata (L. Cretaceous and U. Jurassic), resting on the granite (Archæan), 4 miles southwest of Cañon City, Colorado. Looking northeast. (Darton, U. S. G. S.)

ipse dixit of some expert, our first question will be, *How shall we begin such a chronological series?* That is, How shall we fix on certain rocks containing fossils, or fix on certain fossil types, which are undeniably older than all others hitherto discovered? If we decide that certain "Pre-Cambrian" beds in the Rockies or elsewhere are the oldest fossiliferous rocks hitherto discovered, how are we to explain to an average intelligent beginner in the science, say a college freshman, our *reasons* for calling these the oldest? Can we give substantial reasons for calling these the oldest? Or must he take it on our say-so?

We have already learned that each stratified formation is of only limited horizontal extent, and that, instead of encircling the globe like universal onion coats, each formation occurs only as mere scattered patches here and there. For instance, the Triassic and the Jurassic rocks are absent over most of North America; while over the larger part of Asia there are no Cretaceous strata. The Tertiary beds also are absent from most of Asia. In very many localities, also, these Triassic, Jurassic, Cretaceous, or Tertiary *rest directly on the Archæan or old crystalline rocks.* Over the larger part of Northeastern America, the Pleistocene, or "Drift," reposes directly on the Archæan. Large areas of South America, and practically all of the great interior of Africa, have no fossiliferous rocks at all,—nothing but the Archæan or Primitive. How then shall we fix on certain typical fossils which are really older than all others? In other words, since we do not have fossiliferous onion coats to work with, but merely isolated patches of strata, how are we to find the real *bottom* of the fossiliferous series? And where we do find these bottom beds, how are we to *know that they are the bottom beds?*

Why Not Contemporary? In most localities, we have not more than two or three of the fossiliferous systems represented (and always only partially represented) above the Archæan. At any rate, we do not have to go down very far in any locality to come to the Azoic or Archæan rocks, which clearly antedate all life. The earlier geologists, Sedgwick, Murchison, and others, evidently assumed that those were the oldest fossils in any particular locality which are found thus at the bottom of the fossiliferous series, or next to the Archæan. This was natural enough, so long as they held to the biological form of the onion-coat theory inherited from Werner. But now that we have outgrown this crude idea, and realize that any kind of fossiliferous bed whatever may occur next to the Archæan, one kind occurring thus say in Florida, another in California, another in Southern England, and so on, are we not face to face with the possibility that samples of all these various types of life may have *lived contemporaneously in scattered localities all over the world?* In other words, how are we to prove that there were not distinct floral and faunal districts and regions back at the earliest period of which we have scientific knowledge?

Biological Onion Coats. Or, let us not attempt to start with an absolute beginning, but let us begin, we may say, with the *Cambrian.* Either these Cambrian deposits were once universal,

or they were not. If we affirm that they were once universal, even so far as the ocean was concerned, how are we to prove this affirmation? Certainly they are far from being universal in appearance. In fact, so far as we can actually see and estimate them in any physical way, these Cambrian beds constitute one of the smallest and least widespread of all the fossiliferous systems. It is easy to assume that, if we were to strip off all the other fossiliferous strata, a broad set of these Cambrian beds would probably be found spread out over much wider areas of the Archæan than appears from the surface indications. But so far as we know, samples of every single one of the other formations *might also be found thus in patches resting on the Archæan,* and in such a relationship to these Cambrian beds that no trace of overlap could prove them to be younger and not merely contemporaneous. At any rate, appealing to what we can't see and can't prove is much like the argument of a blind man based on what he can't see,— it is not very scientific.

On the other hand, if we admit that we can not *prove* that these Cambrian deposits were *once universal,* we must either keep on affirming what we admit that we can not prove, or we must admit that while these Cambrian trilobites and brachiopods were living in certain localities, such as Newfoundland, or the high Sierras of California, or Norway, Jurassic ammonites and belemnites were probably also living in other localities, such as Texas or Alaska, and Cretaceous dinosaurs and Tertiary mammals were also living in scattered localities over various parts of the world. In other words, we should have to admit that it is *mere bald dogmatism,* without any scientific facts whatever to support it, to assert that these widely diverse types of life might not all have lived contemporaneously. Certainly there is no scientific way of proving that they did not.

Reductio ad Absurdum. All geologists assume that the life groups represented in the systems — the Cambrian, Ordovician, Silurian, etc.— were successively universal around the world; or at least, it is assumed that they occupied the world exclusively, as no other distinctly different kinds of life were then in existence. For otherwise the strata of these systems would not be of any time-value; they would not represent *all* that was really going on in the world during their respective periods. But these systems are always capable of much subdivision,— first into Lower, Middle, and Upper, and then more minutely. Hence, by the same line of reasoning, *each of these subdivisions must*

likewise have been universal. By this process of subdividing, we finally reach the *formational unit,* which we must also assume to have been universal, or to represent a universal condition; for otherwise this set of beds which we term a formation would not be of any time-value in the general geological series. But this is palpably absurd; *these formations are not universal, and clearly never were universal.* They are always extremely limited in horizontal extent, that is, are *localized;* for we can see their localization and their limits with our eyes.

Hence, as our reasoning has led us into an obvious absurdity, there must be something wrong either with our *method* of reasoning, or with our assumed *major premise.* But the method is as clear and connected as any demonstration in Euclid; therefore the major premise with which we started must be false. In other words, the life groups represented in such systems as the Cambrian, Ordovician, Silurian, and on to the Tertiary, can not represent universal conditions.

What Do the Formations Represent? But the question then very naturally arises, What do they represent? The answer to this is just as obvious: *They simply represent a taxonomic or classification series of the life of the ancient world,* just as living samples might be made up from here and there all over our modern earth to represent the life of the world to-day, these samples being each a representative local fauna or flora from some particular locality here or there over the modern world. For it is simply these buried local faunas and floras with which we are dealing when we speak of the various geological formations; and we have been piecing these scattered formations into systems and into groups of strata, under the impression that they represent various time-values, when they can not represent anything of the kind. The whole geological series is just as purely constructive, just as wholly artificial, as would be a corresponding series of the living plants and animals of our modern world, which might be made up by carefully gathering and arranging many thousands of local faunas and floras from scattered localities all over the earth. There would be no essential difference between the two series, save that the geological one represents dead (and often extinct) forms, while the modern one would represent living ones. And the one would essentially parallel the other, and would also just as clearly represent a "history of creation" as would the other.

To revert to an analogy already used, if we consider the catalogue index of a library, we could doubtless prove our A's and B's and C's to be each universal, just as truly as we do

our geological systems, in the sense that some books under each letter would turn out to have been issued in New York, Boston, Atlanta, Chicago, San Francisco, London, Paris, Berlin, Capetown, Sidney, etc. And then our ingenious antiquary might devise a brilliant theory about the history of the development of printing all over the world, based on this catalogue index, just

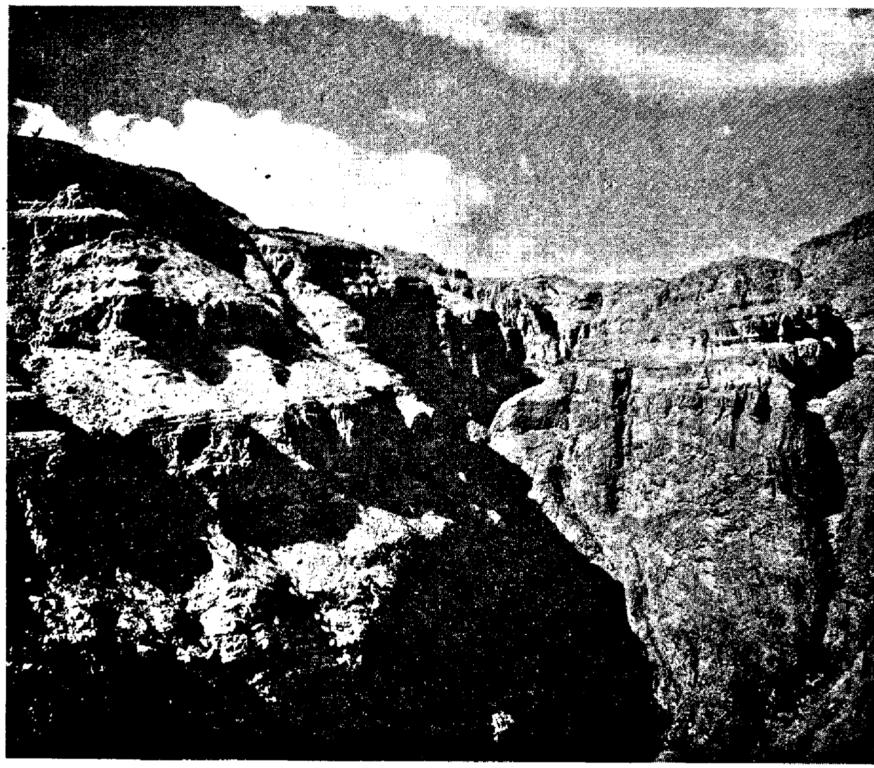


FIG. 417. Tertiary beds resting directly upon metamorphic Archæan, in Red Cañon, east of Mecca, California. (Mendenhall, U. S. G. S.)

as our evolutionary geologists have given us a moving picture of the evolution of life, based on their geological series. And the scheme of this ingenious antiquary would have just as much real historical and scientific value as has the current popular one furnished us by the evolutionary geologists.

General Facts

Relations to the Archæan. But perhaps we should descend from the clouds of these *a priori* speculations, and formulate a few facts about the fossils which we can actually demonstrate.

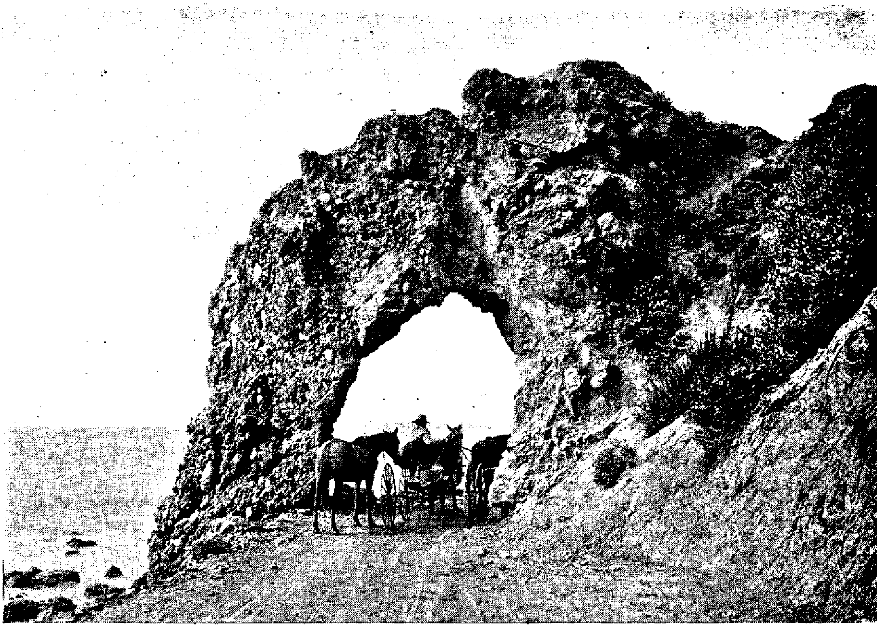


FIG. 418. Natural arch, showing consolidated Eocene conglomerate, on the coast, 4 miles north of Santa Monica, California. (Arnold, U. S. G. S.)

Some of these facts have already been illustrated with so many examples that we need not repeat these examples here. Others will need to be illustrated with specific instances.

I. There is always a marked *nonconformity,* usually an angular nonconformity, between the Primitive or true Archæan and the fossiliferous strata overlying them.

II. Any kind of fossiliferous rock, Tertiary, Cretaceous, Jurassic, Triassic, etc., may rest (nonconformably) upon the Archæan *directly,* without any so-called "younger" strata in between; and these strata thus resting on the Archæan may themselves be crystalline or wholly metamorphic in texture.

For example, through Tennessee, Eastern Mississippi, and into Alabama, the Cretaceous rest on the Paleozoic, "and in Georgia they rest on the more ancient crystallines" (Schuchert); that is, they rest on the Primary or Archæan. Over the Rocky Mountain region, the Triassic beds lie directly upon the Archæan; and the same condition extends down through much of Mexico and Central America. Also in other parts of the region west of the Rocky Mountains, the Carboniferous frequently occur directly on the Archæan. In Cuba and Jamaica, the Cretaceous are in this position; while in California, the Tejon (Eocene) lie

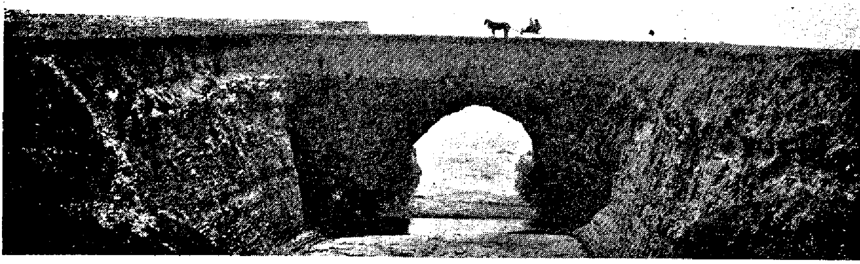


FIG. 419. Natural bridge, in consolidated Miocene shales, half a mile north of the mouth of Meder Creek, Santa Cruz County, California. (Arnold, U. S. G. S.)

directly upon the old granites and gneisses, and are as highly metamorphosed as any of the Paleozoic. In Saxony and Bohemia, the Mesozoic rest upon the Archæan or Primitive; and

FIG. 420. Consolidated Pleistocene gravel, at Lewiston, New York. (Gilbert, U. S. G. S.)

it was on this account that these Mesozoic strata were formerly styled the "Secondary rocks."

These examples help us to understand that Tertiary or Cretaceous strata are about as likely to be found at the bottom or next to the Primitive as are Cambrian, Ordovician, or Silurian; and that these so-called "young" rocks may by every physical appearance as well as by their position, resemble the so-called "oldest" fossiliferous rocks. Geologists always speak of these instances as examples of "overlap," and assume that if these upper strata were followed out far enough laterally,

FIG. 421. Maximus Chapel, in the catacombs of Salzburg, Austria. These rooms were hewn out of the highly consolidated Pleistocene gravels (Nagelfluh). They date from the third century. In its physical characters, this rock is apparently more ancient than some of the Cambrian and Ordovician beds in Northern Russia. (After Grabau.)

other so-called "younger" strata would be found intervening between them and the Archæan. But this is only theory; for in many instances, no such intervening strata can be proved to exist, the upper strata giving out before they can be traced sufficiently far in any direction to prove a superposition on other fossiliferous rocks. From this, it follows like a mathematical demonstration, that when Cambrian, Ordovician, or Silurian strata are found resting on the old crystalline or Archæan rocks, they can not be proved to be intrinsically and necessarily older than those Tertiary, Cretaceous, Jurassic, or Triassic strata found in an exactly similar situation elsewhere. And hence no one of these *systems* can be proved to be really older than any other.

III. Conversely, any kind of fossiliferous strata may over wide areas constitute the *surface rocks,* and may consist of *loose, nonconsolidated materials,* in position and texture thus resembling the "late" Tertiaries or the Pleistocene.

The soft muds and clays and unconsolidated sands composing the Cambrian strata around the Baltic and in Wisconsin, have been mentioned in a previous chapter dealing with these formations. The wide sweep of the Ordovician over much of Russia, consisting of similarly soft, unconsolidated materials, has also been spoken of when we were dealing with these strata. The soft Cretaceous beds of the southeastern Atlantic seaboard and of the Gulf border have also been described; but many other examples might be given from Eastern Asia and other parts of the world.

On the other hand, even the most recent of the rocks (according to the commonly accepted theory), such as the late Tertiary rocks, or even the Pleistocene, may be as completely consolidated as any of the strata classified as very "old." Plenty of examples have already been given in the previous pages; while a few illustrations of this fact are shown in the accompanying illustrations.

Conformity. Having in these three propositions treated of every possible relationship between the fossiliferous strata and the Archæan, we must next turn our attention to the relations between the fossiliferous beds themselves, and see if there are any clear distinctions as to relative age in the manner in which they lie upon one another. We have two principles here to guide us, that of *superposition,* and that of *conformity.* As we have already explained these terms elsewhere, we need not take the time to amplify the subject here. Unless physical evidence of overturning is present, the order of superposition shows the true historical order for the locality; and where there is no manifest erosion or disturbance of the lower beds before the upper ones were laid upon them, it is quite natural to suppose that no great length of time could have elapsed between the deposition of the two sets of strata. In other words, *conformity* means substantially continuity of deposition.

We shall deal with this subject of *conformity* first. And we may state a great general principle regarding the relations between the various strata as follows:

IV. Strata of any of the fossiliferous systems may be found *reposing in apparently perfect conformity* upon the strata of any "older" fossiliferous system.

"Deceptive Conformity." The conditions covered by this statement have been termed "disconformity" by many geologists. Professor W. B. Scott calls such a case a *"deceptive conformity,"* with very obvious expressiveness. For when a formation classed as "young" occurs in obvious conformity upon one called much "older," the beds supposed to be properly intervening being absent, and not even represented by erosion or by any dis-

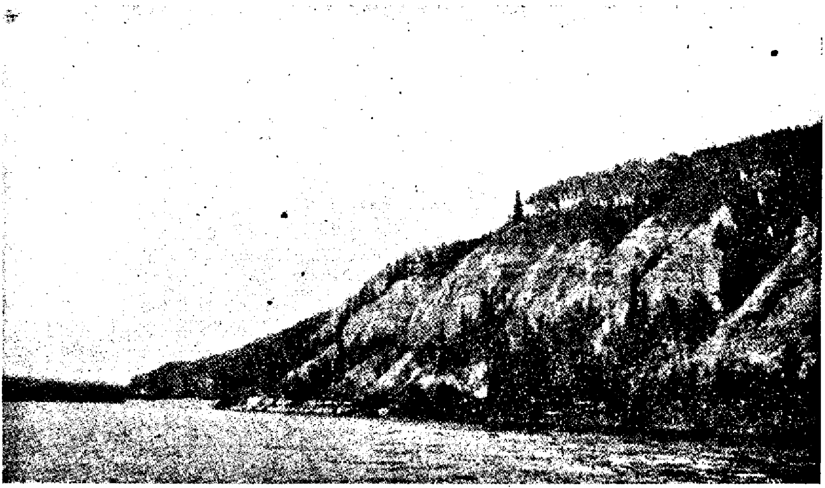


FIG. 422. "Deceptive conformity" of Cretaceous shales on Devonian limestones (at dotted line near the water), 4 miles below Fort McMurray, Athabaska River, Alberta, Canada. (F. J. Alcock, Geological Survey of Canada.)

turbance of the lower beds, it surely is a case to deceive all except those who are well fortified with a preconceived theory as to the true "historical" order.

1. An example was reported many years ago by Murchison, from Northern Russia, at Ust-Waga, on the Dwina, where Pleistocene or "late" Tertiary beds occur in "absolutely conformable superposition on the horizontal Permian sediments." (Suess, "Face of the Earth," Vol. 2, p. 543.)

This is perhaps an extreme case; but there are many where only one or two systems, sometimes only a part of one, are absent. However, in even such a case, the time interval, as estimated by evolutionary geologists, is to be reckoned in thousands of years, perhaps in millions.

2. There is a large area near Lake Athabaska, Canada, where Devonian limestone is conformably covered by Cretaceous beds. The "remarkable persistence" of this "deceptive" conformity, according to an officer of the Canadian Geological

Survey, extends in one direction for fully 150 miles; and yet, over this wide area, according to this geologist, "the vast interval of time which separated the two formations is, so far as observed, unrepresented either by deposition or erosion." ("Annual Report," New Series, Vol. 5, Part D, p. 52.) Indeed, this same succession of strata, Cretaceous upon Devonian, extends

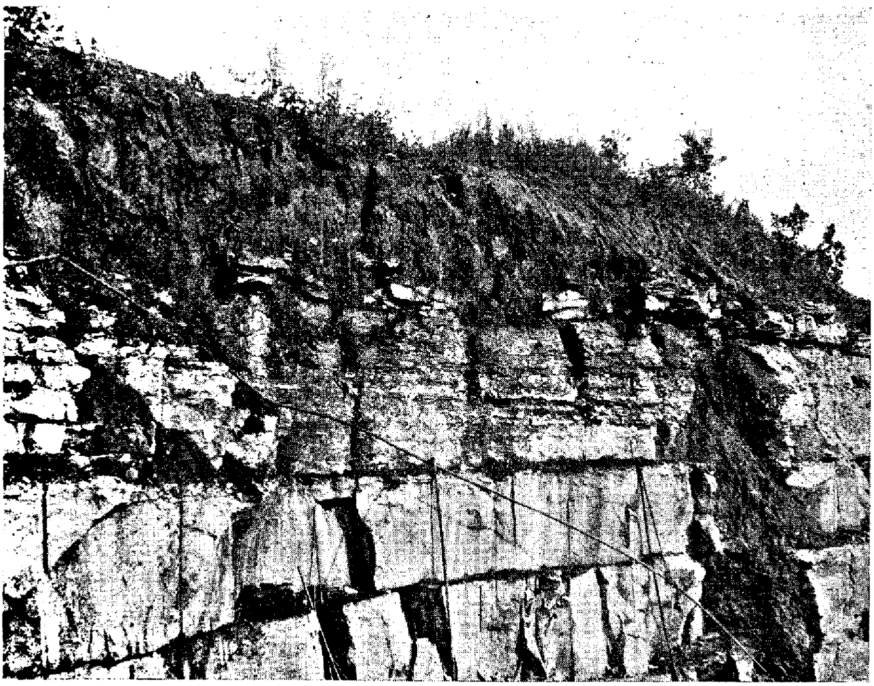


FIG. 423. View in Shanks quarry, on Bear Grass Creek, near Louisville, Kentucky. Looking southeast. Here Middle Devonian strata rest in "deceptive conformity" upon Middle Silurian, the contact line being in the upper heavy layer, just above the white streaks, which are light-colored chert in the Silurian part of the layer. (Butts, U. S. G. S.)

nearly to Lake Manitoba, some 500 miles away; though it would be quite unreasonable to expect even the most honest conformity to cover any such distance.

But very evidently, if we can only discard the life-succession theory, the Cretaceous beds were here laid down quickly after the Devonian; and hence the long millions of years supposed to have intervened between these two systems of rocks can have had no real existence. All theories about diastrophism and base-leveling which have been used to explain such facts as these, are merely efforts to dodge the force of very plain and unequivocal evidence.

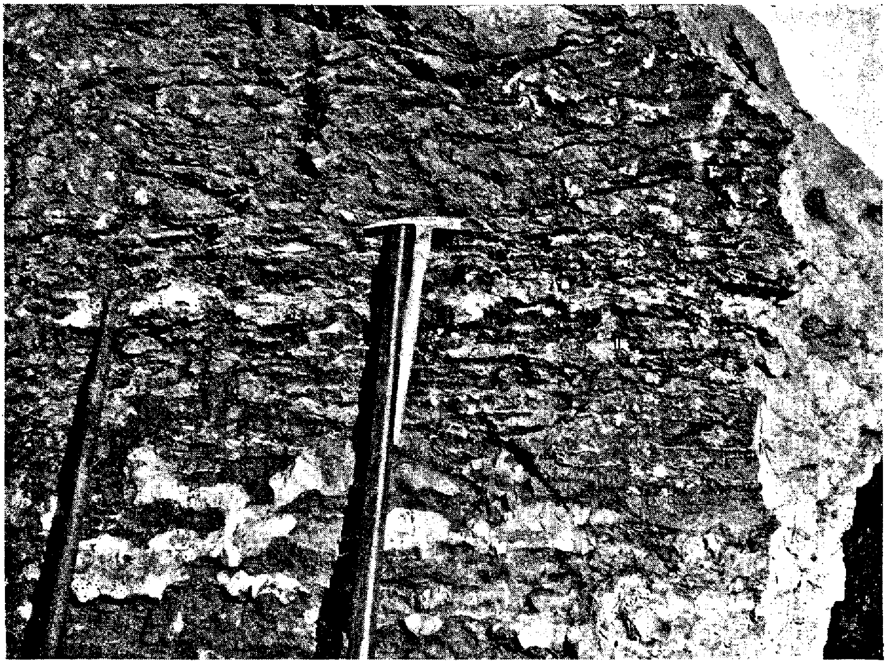


FIG. 424. Close view in Shanks quarry, showing the "deceptive conformity" between the Middle Devonian above, and the Middle Silurian below,— marked by the hammer head. Looking east. (Butts, U. S. G. S.)

3. Another example is near Banff, Alberta, where Lower Cretaceous overlies Lower Carboniferous "without any perceptible break, and the separation of one from the other is rendered more difficult by the fact that the upper beds of the Carboniferous are lithologically almost precisely like those of the Cretaceous" (above them). And the illustrious director of the Geological Survey of Canada, from whom I have been quoting, A. R. C. Selwyn, gives us the further enlightening statement that "were it not for fossil evidence one would naturally suppose that a single formation was being dealt with." ("Annual Report," New Series, Vol. 2, Part A, p. 8.)

These words are surely very full of meaning, and especially when it is remembered that they do not come from some youthful novice, but from one of the most distinguished geologists of modern times.

4. In the Bear Grass quarries ("Shanks" quarry) at Louisville, Kentucky, a Middle Devonian coral limestone lies directly upon another similar coral limestone classed as Middle Silurian. Yet "the absolute conformability of the beds can be traced for

nearly a mile," and "the parting between these two zones is like that between any two limestone beds; but this insignificant line represents a stratigraphic hiatus the equivalent to the last third of Silurian and the first third of Devonian time." (Charles Schuchert, "Textbook," pp. 587, 588.)

5. A similar disconformity of Middle Devonian resting upon Middle Silurian is seen at Newsom, Tennessee. These Middle Devonian are about 6 feet thick, and in their turn are overlain, again conformably, by Lower Carboniferous shales (Mississippian).

6. One might almost think that the Middle Devonian had the habit of following the Silurian in quick succession; for we find this sequence again at Buffalo, New York, though in this case the lower beds are classed as Upper Silurian (Manlius). Still another disconformity occurs a few feet below in this same set of beds; so that this example, like the preceding one from Tennessee, is a double disconformity.

7. In Eastern Tennessee, the Chattanooga black shales, Lower Carboniferous, rest conformably upon the Rockwood gray clays, Lower Silurian, with the whole of the Devonian and more than half of the Silurian absent. Another complication also is added in this instance; for the two formations seem to have

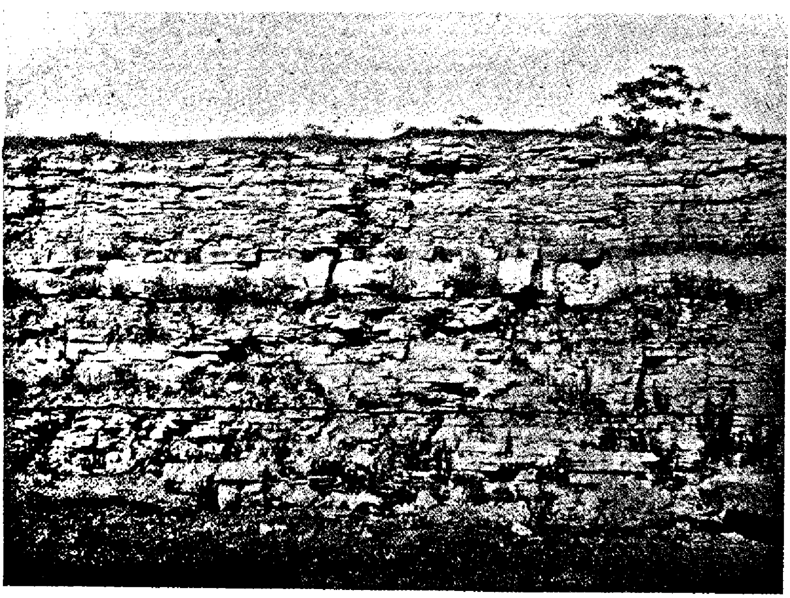


FIG. 425. A double example of "deceptive conformity," near Buffalo, New York. The Middle Devonian (Onondaga) limestone rests conformably on the Silurian (Manlius), the latter in turn resting conformably on the Bertie (Silurian), two formations, the Rondout and the Cobleskill, being absent. (From Charles Schuchert.)

FIG. 426. A case of "deceptive conformity." Jeffersonville limestone (M. Devonian) is seen resting conformably upon Louisville limestone (L. Silurian). The hammer head, just below the hat, marks the line of contact. *Halysites catenulatus*, characteristic of the lower Silurian, is found at the level of the hammer head, with abundant corals, *Favosites* and *Cyathophylloids*, in immediate contact with them above, and characteristic of the Middle Devonian. (Butts, U. S. G. S.)

been mixed up at the point of contact, each one being intercalated with the other in such a way that it is difficult to tell just where the line is to be drawn between them.

8. Throughout four provinces in Northeastern China, Upper Carboniferous beds, chiefly shales, repose directly upon Lower Ordovician limestones, the rest of the Ordovician, all of the Silurian, the Devonian, and the Lower Carboniferous being wanting. According to the closest scrutiny, "the Ordovician and the Carboniferous strata are strictly conformable" (Bailey Willis) over all this region where observations could be made. Indeed, Richthofen, who first examined these rocks, reported them all as belonging to one formation, a Carboniferous limestone.

Space forbids any further listing of specific examples. Sir Archibald Geikie, in summing up the facts along this line, says of these conditions of disconformity, or "deceptive conformity," that they are "not merely local, but *persistent over wide*

areas. . . . They occur abundantly among the European Paleozoic and Secondary rocks," and are "traceable over wide regions." ("Textbook," p. 842.)

Dr. E. O. Ulrich, in speaking of examples of these conditions here in America, says:

"A break corresponding to several geological periods may be no more clearly marked than the relatively brief interruption of sedimentation between two small formations, or between diastrophically distinguished members of a single formation. . . . It makes little difference whether the compared sequences are lithologically similar or dissimilar; *the large hiatuses are, as a rule, no more clearly defined than the smaller breaks.*"—*"Bulletin of the Geological Society of America," Vol. 22, p. 459.*

As for the number and frequency of these examples of "deceptive conformity" or "disconformity," one of the most experienced geologists in America has told the present writer that he himself has seen and examined probably a thousand instances of this character, some of them covering areas as large as several States.

We can well believe Sir Archibald Geikie when he declares that "it is not so easy to give a satisfactory account" of these things. Professor Eduard Suess, in speaking of the "numerous examples" of this sort, declares that they "may well be cause for astonishment." However, the astonishment which I feel

FIG. 427. Panorama showing Chief Mountain and neighboring peaks. All the foreground and the bases of these mountains are Cretaceous. The tops of the mountains are composed of Algonkian limestone. (Willis, U. S. G. S.)

is due to the amazing power of a preconceived theory to blind the eyes and stultify the reasoning powers of the shrewdest observers, when confronted with a series of facts for which their theory has made no provision. Of late years, some ingenious wits think they have worked out a plausible explanation of these facts by a delicate combination of diastrophism and base-leveling, each of precisely the right amount. But a plain

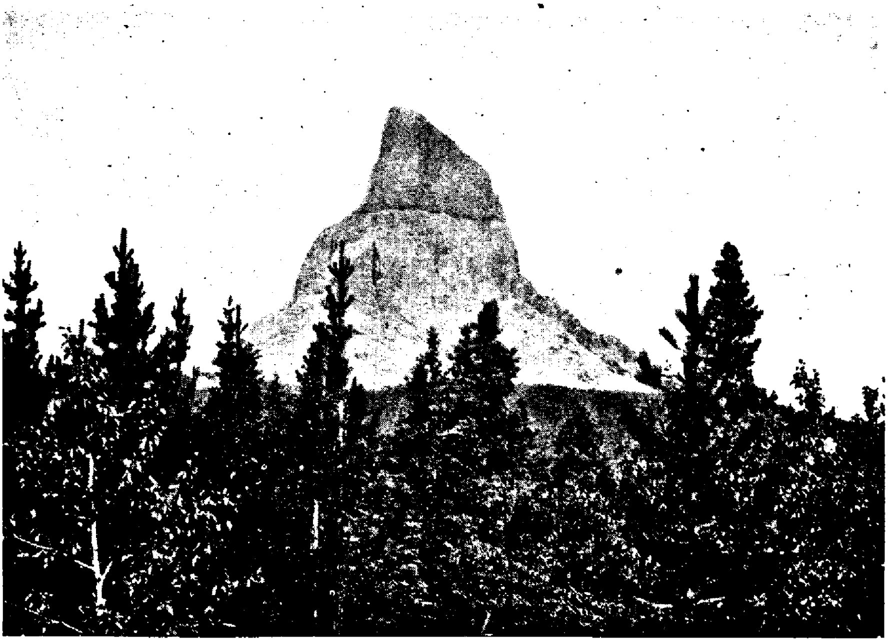


FIG. 428. Chief Mountain, Montana, looking north from Kennedy Creek. This mountain is situated some 3 miles south of the international boundary line. Its top is composed of Algonkian limestone and quartzite, which rest on Cretaceous shales, with every physical appearance of natural conformity. (Stanton, U. S. G. S.)

common-sense view of the matter, which would make such elaborate theories unnecessary, would be to say that these conformities *are like all others of their kind, an obvious proof that these strata followed one another in quick succession, with no great time interval in between;* because the alleged time distinctions between these two contiguous strata are all a mistake, and no such distinctions in age need to be taken into account at all. This solves the whole difficulty, and we then take these conformities just as we do any others,— at their face value. A wrong theory has made a mountainous difficulty, when in reality there is none whatever.

Thrust Faults. But if devoted followers of the current theory have found "cause for astonishment" in these examples of "deceptive conformity," what will they say if we should find an apparent conformity of this kind *upside down,* that is, with the "older" above and the "younger" below, but with just as much apparent agreement in dip between the two,— in short, the two *apparently in actual conformity,* only in the wrong order? In such a case, either the rocks are wrong, or the theory

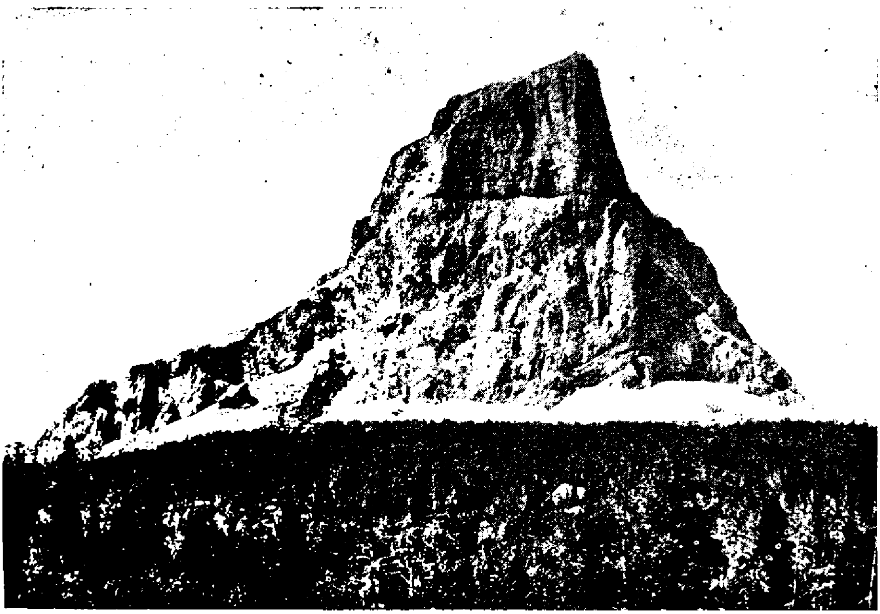


Fig. 429. Another view of Chief Mountain.

is wrong. Will our theorists be brave enough to hold to their theory and give the direct lie to the rocks? If the former examples of conformity were *deceptive,* what name shall be applied to examples where the conformity is so obviously the reverse of all that the theory has taught us for a hundred years?

But there are plenty of examples of this sort also. They are listed among the curiosities of the science of geology, and are called *"thrust faults,"* or simply *"thrusts";* and the theoretical explanation of how the rocks happen to be in this wrong position has been called "one of the triumphs of modern geological research." (Pirsson.) Perhaps; but it may be that the reader of these pages will conclude, after a study of the facts, that this theory of "thrusts" is rather a pitiful example of the

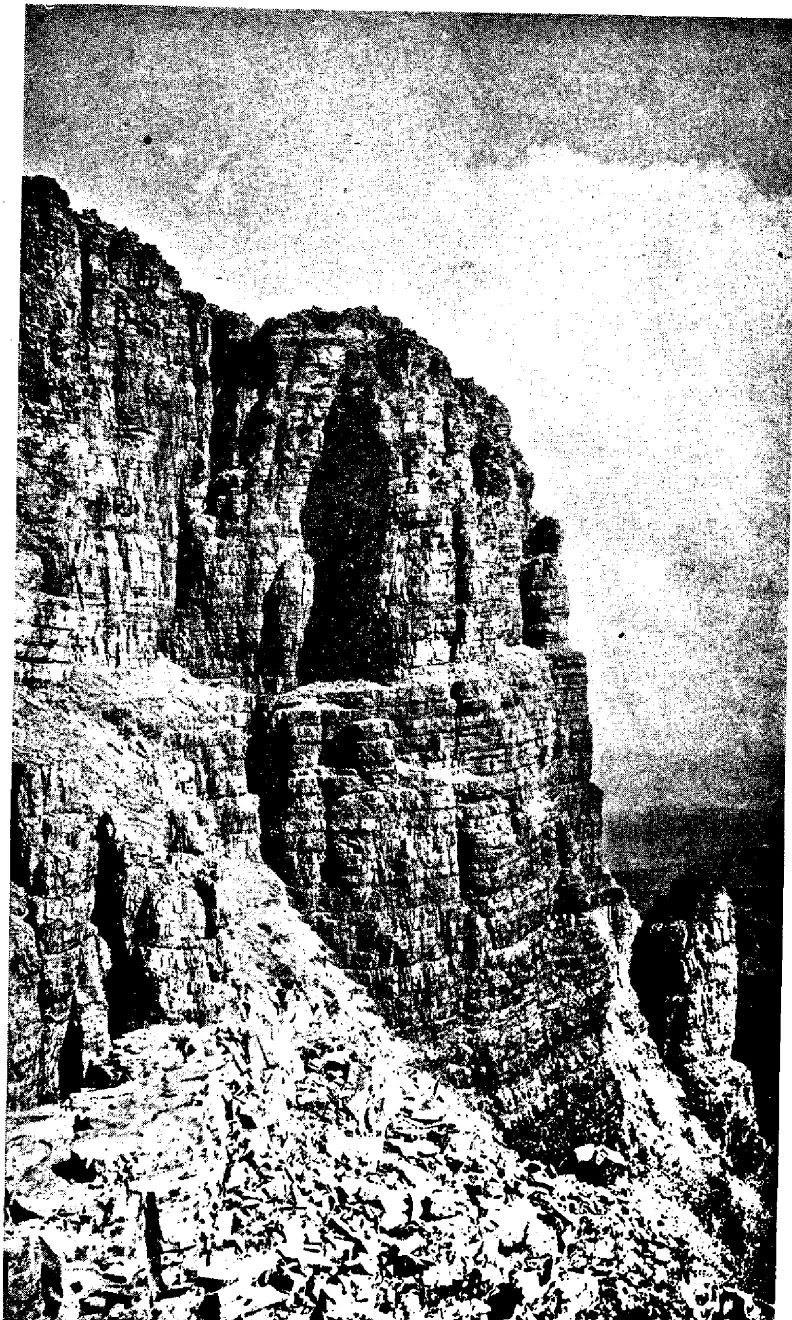


FIG. 430. Southwest face of Chief Mountain, Montana, viewed from the upper slope of the mountain. This is all Algonkian; the Cretaceous appears only much lower down on the mountain. (Stanton, U. S. G. S.)

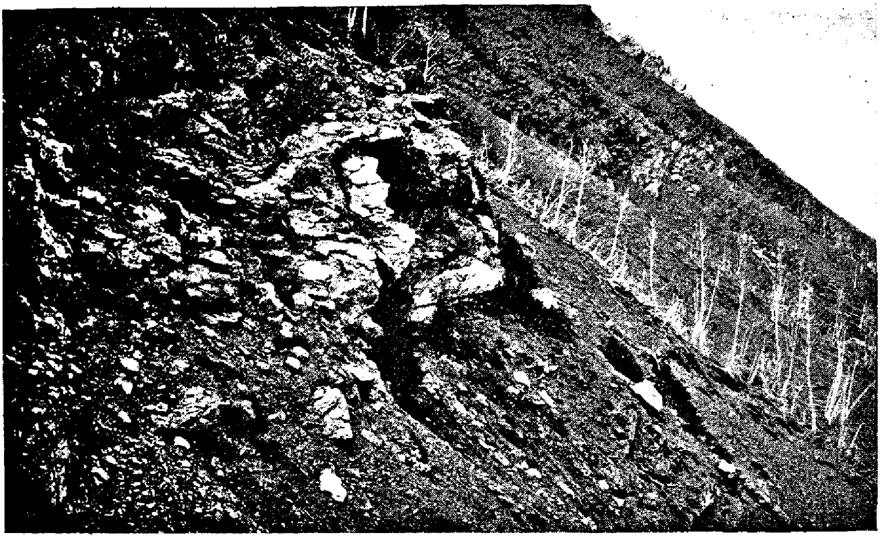


FIG. 431. Algonkian limestone resting on Cretaceous shale, with every appearance of natural conformity. On the slope of Summit Mountain, Glacier National Park. (Stanton, U. S. G. S.)

hypnotizing power of a false theory in the presence of the very plainest facts.

Alberta and Montana. A good example to start with is the region in the Rocky Mountains running from the Sun River, just west of the middle of Montana, up to the Yellowhead Pass, in Alberta, Canada. The district is over 500 miles long, north and south, and of quite indefinable width, though at the international boundary line it is some 30 or 40 miles wide, running back at least to the valley of the North Fork of the Flathead River. South of the boundary line, it includes all of the Glacier National Park. North of the line, it takes in five parallel ranges of mountains running north and south, with four intervening valleys. It takes in all the wild, picturesque scenery around Banff and Lake Louise, and also that around Crowsnest Pass, and includes such picturesque lone peaks or outliers as Crowsnest Mountain, Chief Mountain, and Gould's Dome, the latter being 10,125 feet high.

Over all this vast area, which must measure nearly 20,000 square miles, the mountains present much uniformity, and consist of jointed limestones, argillites, and quartzites, classed as Algonkian (Pre-Cambrian) in all the southern part of the area, and called Carboniferous farther north. But the valleys are all Cretaceous, wherever the rivers have dug out their channels deep enough; for Cretaceous strata run under the mountains in a

nearly horizontal position from the front, or from the east; and to the west of this area (as in the valley of the Flathead), the Cretaceous run under again as before. Of course, it is quite unreasonable to expect any *conformable* contact throughout all this

FIG. 432. Pinnacle (erosion remnant) of Altyn limestone (Algonkian), resting on coal-bearing Cretaceous shale and sandstone, on the divide running southwest from Chief Mountain, Montana. (Stanton, U. S. G. S.)

immense area. Yet, where good exposures can be obtained, as at the base of Crowsnest Mountain and Chief Mountain, and at many points along the front of the Glacier National Park, also to the north, the apparent conformability is perfect. The picturesque peaks just mentioned, as well as the entire Glacier

Park, may well be described as Paleozoic islands floating on a Cretaceous sea; for the Cretaceous runs under these mountains *from every side,* just as the soil runs under a building.

There are minor disturbances, as could not but be expected in an area of these dimensions. Yet, the undisturbed character of most of these mountains is quite remarkable. Merely a gentle dip here and there is observed in the clearly defined strata com-

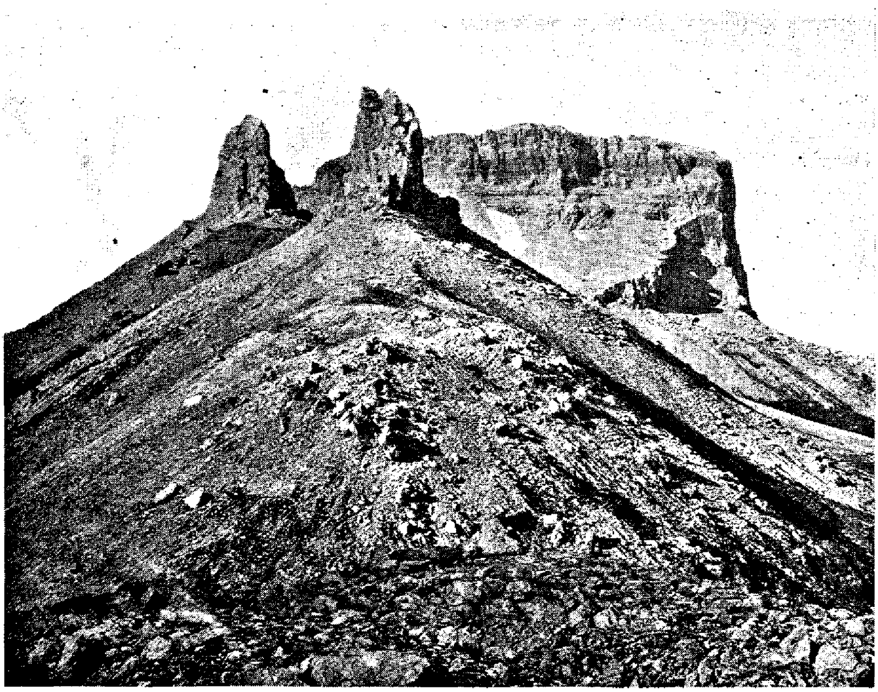


FIG. 433. Chief Mountain and its satellites. The pinnacles in the middle of the view are erosion remnants of Algonkian limestone resting on Cretaceous sandstone, the latter containing coal seams. All the upper part of the mountain proper is also composed of Algonkian rocks. The sloping part is Cretaceous. Glacier National Park, Montana. Willis, U. S. G. S.)

posing the tops of peak after peak extending across the sky line, the whole area looking like undisturbed horizontal strata worn away into mountains of erosion. Were it not for the order in which the popular theory says that these strata *ought* to occur, no one would ever dream of anything else than that over all this area, the Cretaceous strata were laid down *first,* and these Paleozoic and Algonkian beds were laid down quite quickly and rapidly afterwards.

R. G. McConnell, of the Canadian Survey, speaking of the very natural appearance of the upper and the lower strata near

Kananaskis Station, on the Canadian Pacific Railway, says that the line between them "acts exactly like the line of contact of two nearly horizontal formations," while in a natural section made by the Ghost River a few miles away, the two sets of beds "appear to succeed one another conformably." ("Report" for 1886, Part D, p. 33.)

Other Examples. Other examples of strata in this reverse order are to be found almost everywhere. One of them is in the State of New York, and runs up across Vermont into Quebec. Another in the southern Appalachian chain is a well-known

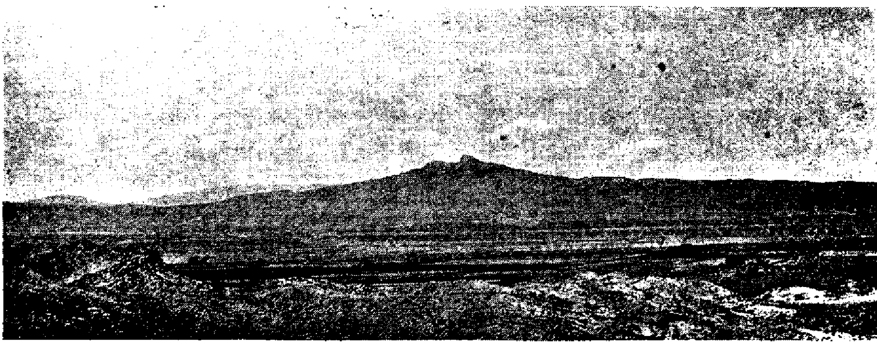


FIG. 434. Hart Mountain, from 3 miles east of Cody, Wyoming. The cap of this mountain is composed of Madison limestone (L. Cretaceous), and rests in apparent conformity on Eocene beds. This cap is manifestly an erosion remnant which was once continuous with the cap of Chalk Mountain, some 15 miles to the southwest. Doubtless a sheet of this strata once extended over all this region. The theory of a gigantic "thrust" is merely an attempt to save the old theory of the "invariable" order of the fossils. (Hewitt. U. S. G. S.)

instance; it involves parts of Georgia, Alabama, and Eastern Tennessee. Here Cambrian or Lower Silurian lie in apparent conformity upon Carboniferous; and the line of contact has been made out as extending 375 miles in length. The so-called "Bannock overthrust" is some 270 miles long, covering parts of Utah and Idaho to the northeast of Great Salt Lake. Many other examples might be given from various parts of North America.

In the Highlands of Scotland are other examples famous in the history of the science, because Sir Archibald Geikie, one of the first to examine these localities, described these strata as naturally conformable. Afterwards, when others had visited the localities and had found "younger" fossils in the lower beds, the whole description of the country had to be revised in accord with the traditional theory; but Geikie, who was then the director of the Geological Survey of Great Britain, excused his former "mistake" by saying:

"Had these sections been planned for the purpose of deception, they could not have been more skillfully devised, . . . and no one coming first to this ground would suspect that what appears to be a normal stratigraphical sequence is not really so."—*"Nature," Nov. 13, 1884, pp. 29-35.*

Examples of the strata in the "wrong" order were first reported from the Alps nearly half a century ago. Since that time, whole armfuls of learned treatises in German, in French, and in English have been written to explain the wonderful conditions there found. The diagrams that have been drawn to account for the strange order of the strata are worthy to rank

FIG. 435. Erosion remnant of Bighorn limestone (Ordovician) overlying Tertiary beds, East Peak, McCulloch Peaks, Bighorn Basin, Wyoming. (Hewitt, U. S. G. S.) This is a part of the so-called "Hart Mountain overthrust," where Carboniferous limestones comprise the tops of several peaks, with much younger (Eocene) strata underneath.

with the similar ones by the Ptolemaic astronomers picturing the cycles and epicycles required to explain the peculiar behavior of the heavenly bodies in accordance with the geocentric theory of the universe then prevailing. The geological theories to explain the findings in the Alps have gone through many vicissitudes, and have been repeatedly revised. At the present time, the theory generally received is that the rocks now composing the Lepontine Alps were lifted up several thousands of feet and *pushed bodily northward some 60 miles into the Helvetiac region,* where erosion has since carved them up into the mountains as we now find them. Several other "thrusts" of this character are described from the Alps, one of them involving the famous Matterhorn, which Schuchert describes as "a mighty mountain without roots, a stranger in a foreign geologic environment."

In Scandinavia, a district some 1,120 miles long by 80 miles wide is alleged to have been pushed horizontally eastward "at

least 86 miles." (Schuchert.) In Northern China, one of these *upside-down* areas is reported by the Carnegie Research Expedition to be 500 miles long.

Scientific Methods. A multitude of other examples might be listed from almost every quarter of the globe which has been at all carefully examined. But to describe them in detail would take a volume of itself. It is not a question of more examples,

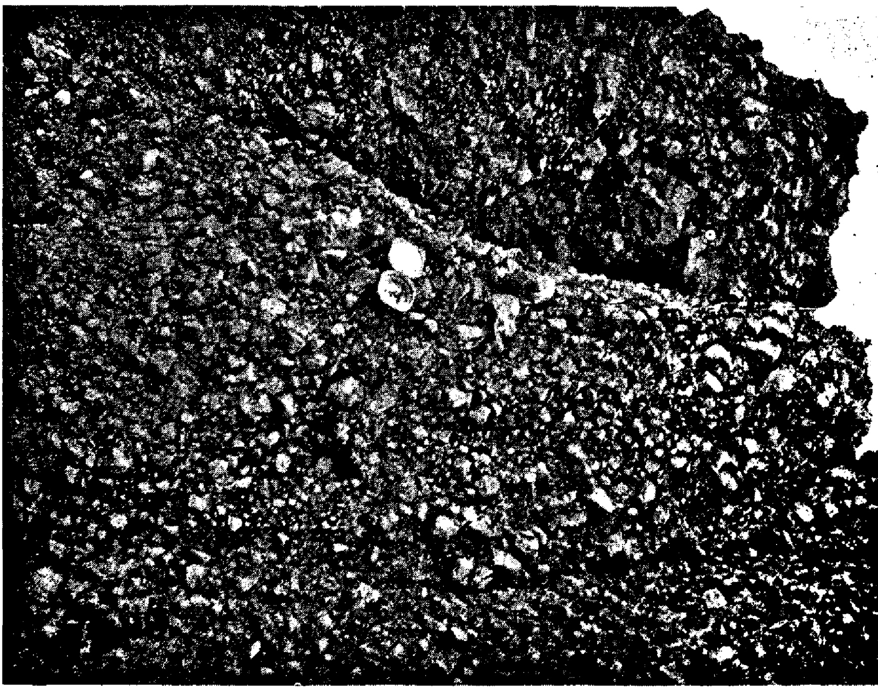
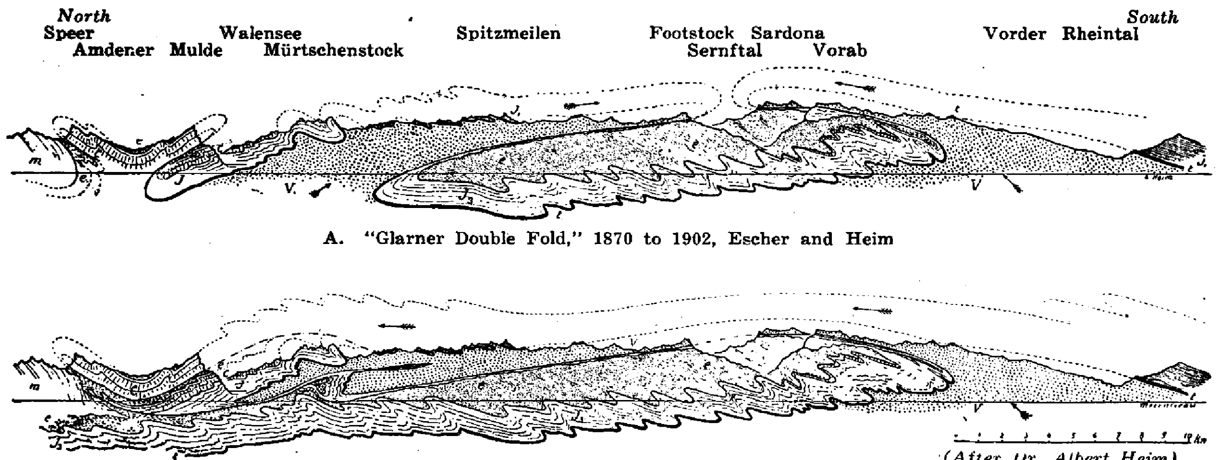


FIG. 436. Details of Madison limestone on East Peak, McCulloch Peaks, Bighorn Basin, Wyoming. (Hewett, U. S. G. S.)

but a question of how we are to understand the examples which we already have.

When examples of strata in the "wrong" order first came to the attention of geologists, it was suggested that a great *fold* had once been pushed up and completely overturned, erosion having taken away the upper layers of the fold, leaving only the older strata on top of the younger. Such an explanation seemed plausible in regions of complicated structure, like the Alps, and especially where there seemed a serial repetition of the same beds several times in the same vertical section; though even here it was only a case of inventing some compli-



A. "Glarner Double Fold," 1870 to 1902, Escher and Heim

B. "Glarner Thrust-fault," 1883 Bertrand, 1892 Suess, 1903 Heim

m — Molasse (Middle Tertiary)
e — Flysch (Lower Tertiary)
C — Cretaceous
J — Jurassic
t — Triassic (Röthidolomit)
V — Verrucano (Permian)

FIG. 437. THE UPSIDE-DOWN CONDITIONS AT GLARUS, SWITZERLAND, AS VARIOUSLY INTERPRETED.

From these two diagrams, it is seen that what was formerly called a "double fold," with the Jurassic and Triassic strata folded in from both sides toward the Sernf Valley, is now called a "thrust fault," with the rocks all pushed one way. This change of interpretation is *prima facie* evidence that there is no physical evidence here of any real overturning of the strata. The fossils are here in the wrong order; that is all. And the succession looks as natural as any other succession of strata elsewhere. If we could forget the traditional theory, we would say that these strata were actually laid down in the order in which we find them. This is the only sensible view of the matter, the only scientific view. Both of the fantastic speculations embodied in the two diagrams given above, are unworthy of serious attention from truth-loving people who are not committed to an *a priori* theory of how the strata *ought* to be found.

cated device which would save the theory of the traditional order of the fossils, for there was no physical evidence of any such incredible overturning.

Later, however, similar reversed conditions were found in regions like the southern Appalachians and in the Rockies, where the strata looked practically horizontal, with little or no signs of any disturbance. Then the theory was modified so as to provide for a sharp break or rupture of nearly horizontal strata, and the pushing up of the one set of strata over on top of the other, after which erosion is supposed to have removed all but the lower layers of the thrust block, leaving them now lying in a natural-looking position upon the strata which are really younger. Thus the former explanation of an "overthrust fold" has generally been replaced by that of a *flat-lying "thrust"* or *"thrust fault,"* in the language of the current theories. But all such incredible movements of the strata are necessitated by the simple fact that the fossiliferous strata happen to be found in the wrong order, and as Dr. Albert Heim once expressed it in a letter to the present writer, "the most incredible mechanical explanation is more probable than that the evolution of organic nature should have been inverted in one country as compared with another."

But I confess that I do not understand such a style of argument. It seems to me that this method of reasoning belongs to the Middle Ages, not to the twentieth century. Surely the order in which the rocks (fossils) were laid down all over the earth must always at best be only a theory. We may have found them occurring in a certain relative order for a thousand times; but are we to deny the positive evidences of our senses, if we should at last happen to find them occurring in some other than the accustomed order? My training in natural science has never taught me that a theory should have the right of way over facts in any such fashion as this. What progress would the world have made in physics, or chemistry, or bacteriology, if we had not thrown bushels of theories out of the window, whenever these theories were plainly and unequivocally contradicted by real facts? In another communication to the writer, the distinguished scientist of Switzerland just quoted says: *that* the strata are thus in a reversed position over immense areas "is a fact which can be *clearly seen,— only we know not yet how to explain it in a mechanical way."* I prefer to take the most obvious explanation at hand, namely, that *the rocks were actually laid down as we find them;* and if any theories do not agree with these facts, so much the worse for the theories. I

do not believe that it is safe, in any of the natural sciences, to reverse this method, and let theories dominate our views about the facts.

Nor can I agree with the eminent Scottish geologist already quoted, who seems to insinuate that these conditions of the strata have possibly been planned by nature for the purpose of deceiving us, perhaps to test our ingenuity in explaining them. I think we shall be treating nature with more respect if we take her messages at their face value, instead of assuming that they are *written in code,* and that we must decipher them as best we may in accord with *a key which we possess.* We can be better employed than in trying to decode the plain statements of nature

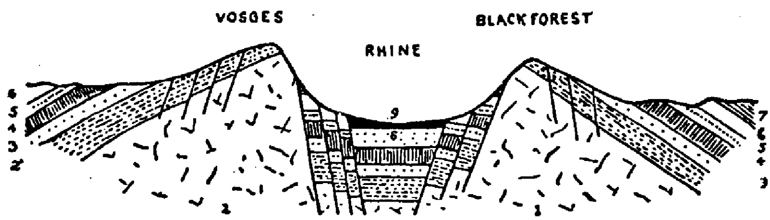


FIG. 438. Diagram across the Rhine valley, showing the Mesozoic rocks on each side, with Tertiary and Pleistocene rocks in the valley. It should be remembered that the vertical proportion is enormously exaggerated, and that there is no absolute proof of the faults at the sides of the valley which appear in this diagram, and which have been placed here as a theory to help explain why these rocks are in the wrong order. This is called a "rift valley," or "graben," by the theory. 1, granite; 2-7, Mesozoic rocks; 8, 9, Tertiary and Pleistocene. (After Lake and Rastall.)

in accord with any such key, no matter if this key has been rendered honorable by a century of use and by the confidence of the most illustrious names in our country's history.

In Every Possible Relative Order. If now we attempt to put together the facts which we have learned in this chapter, we shall find that we have had examples of the strata occurring in practically *every order of serial relationship.*

We first had numerous examples of strata at the top of the geological series occurring *conformably* on any of the strata farther down in the list, the intervening being wanting. Now we have this condition *reversed,* and have any of the strata at the bottom of the list occurring conformably on top of any others farther up in the series. If we put these two classes of facts together, we shall have the great *law of conformable stratigraphic sequence,* which may be stated as follows, and which is by all odds the most important law ever formulated with reference to the order in which the strata occur:

Any kind of fossiliferous beds whatever, "young" or "old," may be found occurring conformably on any other fossiliferous beds, "older" or "younger."

Of course, we have not in this chapter presented anything like examples of *every possible* combination of the strata, such as this law speaks of; that would be a large matter. It may be that scientific discovery has not yet found examples of every possible combination; that itself would be a very large matter. But scientific discovery has been made of quite sufficient examples, and we have even in this chapter presented sufficient examples, to justify this broad general statement, or scientific law. And it is perfectly obvious that no puerile statement about the invariable order of sequence in which the rocks always occur, can stand for a moment in the face of this law of conformable sequence. This law forever puts an end to all evolutionary speculations about the order in which the various plants and animals have developed, in the minds of those who are correctly informed regarding these facts. This law alone is quite sufficient to relegate the whole theory of organic evolution to the lumber room of science, there to become the amusement of the future students of the history of cosmological speculations.

"Extinct Species." The subject of "extinct species" must be briefly referred to ere this chapter is closed. It is an intricate subject for the beginning student, and only the outline can be considered here.

By many, the facts connected with this subject are supposed to furnish a line of evidence in favor of the geological series as a true historical order, and to furnish this evidence quite *independent* of anything hitherto considered in this chapter. The claim is made that all the species of the so-called "older" rocks, such as the Cambrian, Ordovician, Silurian, etc., are *extinct*, many of even the genera being unrepresented by any living forms; but that as we gradually approach the "youngest" rocks, as the Cretaceous and the Tertiaries, the fossils of modern living species appear more and more commonly, until in the Pleistocene all the invertebrates and some even of the higher forms are identical with those now living. And it is argued from this that those formations all of whose species are extinct must necessarily be vastly older than those others which contain many species now alive.

But the following facts must be considered in connection with the claims of this line of argument:

1. This argument is *based on the assumption of uniformity* in its most extreme form, for it denies the possibility that the

modern living species and genera may be merely the lucky survivors of tremendous earth changes in which their contemporaries perished; and this possibility must be candidly faced in any investigation of these questions which pretends to be an impartial scientific investigation. To assume uniformity is to prejudice the case from the start; and this is not a scientific method of procedure. If there has been anything like a world catastrophe, this assumption of uniformity would forever ignore and disguise this fact, and would continually rule out of court any and all evidence pointing in that direction; which is a wholly unscientific attitude of mind.

2. There are several reasons why, if there really was a world catastrophe, very many of the lower forms of life would probably be exterminated, especially such bottom feeders as trilobites and brachiopods and others of like habits. And as the Paleozoic and even the Mesozoic group are composed largely of these lower forms of life, the results as we have them, and to which appeal is made as evidence, are *only just what we should naturally expect* on the supposition of such a world catastrophe. In other words, this supposed evidence is capable of *another easy explanation* which is directly opposed to the conclusion based upon it.

3. This idea of extinct species belonging properly in the "older" rocks, and of a gradual approximation to the living floras and faunas, has constantly *been kept in mind* by the experts who have been intrusted with the work of deciding the exact "age" of all newly discovered strata. Even formations long known have in many instances been changed from one system to another on the testimony of these experts, the proportion of living and extinct species in these formations, and the degree of their approximation to the living floras and faunas, having been the chief factors in making these changes. That is, the fossiliferous rocks from all over the earth have been classified largely with *this very principle in view;* and hence it is not at all strange that the classification as now complete should conform quite generally to this idea of extinct species largely predominating in the so-called "older" rocks. In short, *the witness has been coached to testify as desired,* and hence is not competent to testify. It is difficult to understand how the results of such a purely artificial arrangement of the strata should ever have been suggested *as evidence* that the geological series presents a gradual approximation to the present order of things among the plants and animals.

4. There is abundant and unmistakable evidence of a great world catastrophe of *some sort,* involving a sudden and very extreme change of climate over the Northern Hemisphere at least, with very extensive changes in the distribution of the ocean and the dry land, since man and thousands of living species came into existence, even according to the present accepted system of classifying the strata. But may not this great world change have been the *cause of the extinction* of multitudes of the species which we are so often told must imply the lapse of long ages of time? Is there any way to make a scientific distinction between those extinct species which may have been exposed to such a world convulsion, and to decide that only a certain limited few were made extinct by this event, and then to arrange the others off on the percentage system, *as if no such event had ever happened?* If a dozen burglaries have been committed in a certain vicinity, and a certain notorious criminal has been convicted of having done one of these "jobs," how is he going to avoid the strong suspicion of having done most of the others?

5. Repeated references have been made in the previous chapters to genera and families which seem to *skip* one or more of the systems, and also many genera and families long supposed to be extinct, and found as fossils only in the Paleozoic and the Mesozoic rocks, but discovered in modern times in numerous unsuspected places over the world. There is the further certainty that many other kinds alleged to be extinct are not really separable from others alive to-day, though it is impossible to determine how many such examples may be found among the lower forms of life. At the present time, this subject is in too confused a condition to determine the real facts in the case.

Summary. We may summarize the five points just enumerated, by saying that any alleged chronological distinctions between different formations, based on this idea of extinct species, have *no scientific value whatever.* Hence the value of the geological series as a true historical order, gains no support whatever from this principle of extinct species, just as we have already seen that it is without a vestige of support from the order in which the fossils occur in the strata.

The geological series of the various successive formations is a purely artificial contrivance, convenient enough if made to keep its proper place as a mere artificial arrangement, but without any scientific support as representing a real historical order, when examined either from the history of the science or from the facts of the rocks as we now know them.

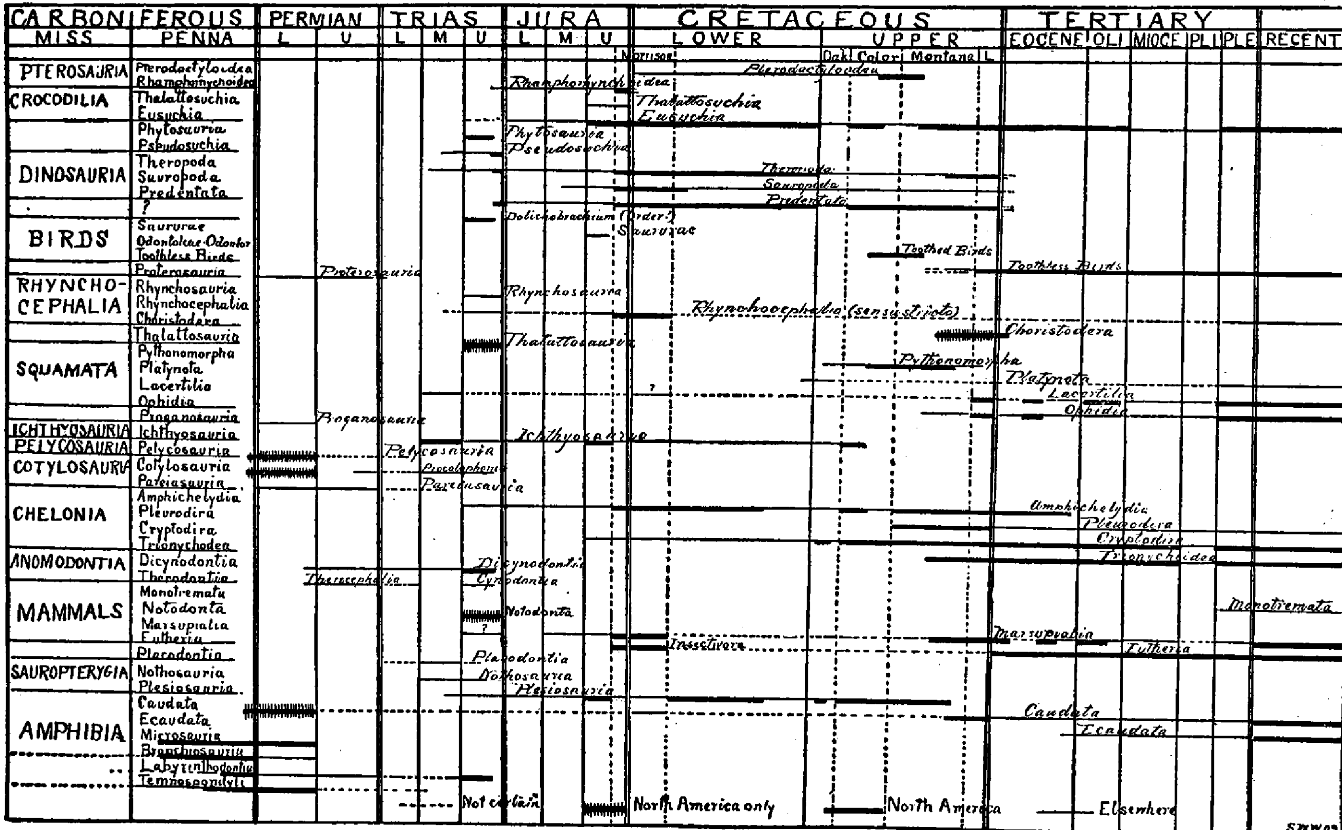


FIG. 489. Chart showing the geological distribution of the chief vertebrates. Notice the many examples of "skipping." (After Williston.)

In conclusion, it should be stated that the ancient world, whose ruins we now find as fossils, was doubtless a *well-balanced unit*, and is to be regarded as merely an older state of our present world. All the important orders of plants and animals living in our modern world have now been found in the fossil state; and the classification of their fossils does not represent a serial or chronological order any more than does a similar classification of the *modern* plants and animals. The one series is merely the complement of the other. The geological series of plants and animals represents merely taxonomic relationships; it is the systematic or classification series of an older state of our world,— of the antediluvian world, if we accept the language of the new catastrophism.

CHAPTER XXXIX

The Circumstances Under Which the Fossils Occur

Uniformity Only a Theory. For nearly a century, or ever since the publication of Lyell's "Principles of Geology" (1830-1833), geologists have assumed that all the rock deposits of the past were made much as rocks are being made to-day, by commonplace causes. This is called the doctrine of *uniformity,* or *uniformitarianism;* and this doctrine has so long and so completely dominated scientific investigation that in effect it has become an iron dogma which rules out of consideration all evidence not agreeable to its teachings. The argument seems to be, that anything contrary to uniformity is impossible; hence no amount of evidence can ever prove anything contrary to uniformity.

But we must always keep in mind that this idea of uniformity is *only a theory;* and like all other theories, it must constantly be measured up alongside the facts. And the opposite idea, namely, that a great world catastrophe may have happened to our world in the long ago, should *always be kept in mind also as the alternative.* The latter has as good a right to a hearing as has the former; and it is also *just as scientific* a hypothesis as the other. And a true study of the facts of geology, if this science is good for anything at all, ought to be able to *settle the matter* very positively in favor of the one or the other of these rival theories.

For these two theories are in direct antagonism; the one is the direct denial of the other. We are done with the old burlesque of a long succession of catastrophes, in serial order, as taught by Cuvier and his followers. If we are to consider the theory of a world catastrophe at all, we must take it as it comes to us from the oldest and most venerable history of the human race, in which it appears as a veritable overturning of all the quiet and regular action of the elements, earth, and air, and water; and such an event can never be made to fit into any scheme of uniformity. The hypothesis of a flood or a deluge is that of a great world catastrophe, absolutely universal in its sweep, wholly abnormal, and essentially different from any event which has taken place under scientific observation, and of incalculable violence and power; and *if there ever was such an event,* this theory of uniformity can not be true. The two

ideas are antagonistic and mutually exclusive. Each theory is on trial; and the evidence from the rocks must decide the one or the other to be the probable explanation of how the major part of the geological changes took place.

Acknowledging a Flood. It is true that some of the best-known of modern geologists, such men as Howorth, Wright, Prestwich, Suess, and Sir William Dawson, have admitted or have undertaken to prove that there must have been *some sort* of catastrophe, like a partial flood, since man appeared upon the earth. But all these men, save perhaps the two first mentioned, seem to labor under the strange inconsistency of supposing that such an event could occur without leaving abundant and indelible proofs of its work in the rock deposits which it would leave behind and in the species which it would exterminate. For when we consider the delicate and complicated mechanism of our world in respect to its climate and the distribution of the land and the water, we must own that any profound disturbance of this delicate equilibrium would easily send the waters of the ocean careering over the land, burying and exterminating myriads of living creatures both in the ocean and on the land, churning them all up together, until no one could estimate the quantity of stratigraphical work accomplished or the numbers and the kinds of species which would be exterminated, before equilibrium could be restored.

Methods of Investigation. From all this, we conclude that, by following true principles of scientific investigation, we ought to be able to decide very positively whether or not any such event has ever happened to our world. A true induction, if it is good for anything at all, ought to be able to find out for certain whether or not the present regular and mild action of the elements has always prevailed in the past; so that there would be no need of assuming uniformity beforehand and then reading all the records of the past in the light of this assumption.

But the theory of uniformity was first taught when the scientific world knew nothing of the life at the bottom of the ocean, and when the most absurd notions were commonly taught about the mechanical and chemical conditions prevailing there. The whole geological series was blocked off, and much of the details arranged, *before* any of the leading scientists would acknowledge that man or any of the living species of plants and animals had anything whatever to do with these geological changes, or that actual representatives of our modern living forms were found as fossils in *any* of these ancient rocks. The fossil world was considered as entirely separate and distinct

from the modern one; the two worlds were regarded as separate, having nothing at all to do with each other. People still treat this doctrine of uniformity, not as a mere hypothesis to be tested according to the evidence, but as a Procrustean law to which every newly discovered fact must be made to conform either by lopping off or by stretching.

But it is absurdly unscientific to assume uniformity and thus to decide beforehand just how the various geological deposits took place, and then throw out of consideration any and all evidence which does not seem to agree with this Procrustean law. If a coroner, called upon to hold an inquest, were to content himself, after the manner of these uniformitarian geologists, with glittering generalities and average statistics about how people are all the time dying of old age, fever, and other causes, coupled with assurances regarding the quiet, regular habits of all his fellow citizens, we could not admire the scientific methods which he employed, if there was clear and ample evidence that the poor fellow under consideration had been shot. Just so with this doctrine of uniformitarianism; it is not approaching the subject in a judicial manner. It is not following the method of true scientific research, but the medieval method of scholastic dogmatism. The geological formations are not regarded as presenting materials for solving the problem of the past of the earth, but as materials for illustrating a preconceived theory of the present order of things prolonged and projected indefinitely into the past. Hence it is not much to be wondered at that under the tyranny of such a doctrine, the science of geology has made little or no advance in its theoretical aspects and in its methods during the past three quarters of a century, though during this period all the other sciences have been making astonishing progress.

But we must reserve the further consideration of this part of the subject until the next chapter, and give here some of the facts which have been discovered regarding the condition in which the fossils are found, that will furnish us with data for estimating how they were buried. Because, although our science has made little or no progress for nearly a century in its general theory and methods of reasoning, it has indeed accumulated a vast amount of data, which ought to be sufficient for a complete reconstruction of the science of geology; just as the patient and exact observations of the Ptolemaic astronomers, accumulated during many centuries, furnished Kepler and Newton with the means of reconstructing the science of astronomy. The reform and reconstruction of geology is the

next great advance to be made in modern natural science; and the present author will consider his mission accomplished, if this volume contributes even slightly toward such a result.

Modern Conditions. Several of the preceding chapters (chapters 5-13) have been devoted to an examination of the way in which modern rock deposits are now being made by our rivers and oceans. Our rivers carry a great variety of materials, and while they sort these materials slightly, they do not form any wide or extensive deposits of one kind of materials alone; these materials are all more or less *commingled,* and do not present that clear distinction between gravel and sand and clay which we find so markedly in evidence in most of the Paleozoic and Mesozoic strata. And the fossils buried by modern streams and rivers are meager and fragmentary in the extreme.

Along the coasts of our oceans, it is true, great stretches of gravel or sand or mud are being separately made, and the various materials are kept more or less distinct. But the fossils now being buried in these deposits are also quite fragmentary, and are limited to the kinds of life inhabiting the littoral zone. We have learned that in the pelagic waters, the ocean currents are confined to the surface waters, and have "no sensible mechanical effects, either in the way of transportation or abrasion." (Dana.) And because of the precipitating effects of salt water, none of the sediments from the land get beyond the classic 100-fathom line, which marks the edge of the continental shelf, and in most cases is not very far from shore. Over all of the true ocean floor, there is no gravel, no sand, no true clay derived from the land surfaces, and no true stratified deposits of any kind are now being formed there; for the waters are so eternally calm as not to disturb the softest ooze. These various oozes, indeed, cover the entire ocean floor; but nothing could interbed these with sand and gravel and land fossils, as we constantly find them interbedded in the ancient rocks, except a tremendous disturbance of the ocean to its very bottom, such as has never occurred since the dawn of scientific observation.

Sir Archibald Geikie thus draws the contrast between the present deposits on the ocean bottom, and the deposits which we find composing the fossiliferous strata:

"Thanks to the great work done by the *Challenger* and other national expeditions, we have learned what are the leading characters of the accumulations now forming on the deeper parts of the ocean floor. So far as we know, they have no analogues among the formations of the earth's crust. They differ, indeed, . . . entirely from any formation which geologists have considered to be of deep-water origin."—*"Textbook," p. 929; edition of 1903.*

Driven from the ocean proper, geologists have made heroic attempts to explain all the formations composing our lands in terms of the shallow-water deposits of the continental shelf, including the estuaries and deltas of large rivers. But it is interesting to watch the methods of reasoning employed. As we have already seen in the previous chapters, we have in the fossiliferous strata repeated examples of the *life* represented in the deep-sea oozes interbedded with *sediments* from the land. And so when confronted with radiolarian or diatomaceous or globigerina remains in clean, thick beds interstratified with sands or clays which perhaps contain land plants or land animals, geologists have tried to picture how the plankton of the oceans must be thrown down along with the sediments forming at the mouths of large rivers. Of course, they can not show how any noticeable *quantity* of this plankton is here deposited, and thus can not show any similarity worthy of the name between modern estuarine and delta deposits and the anciently formed beds; but they have done the best they could to apply the theory of uniformity, and profess to be satisfied with the results. But the contrast must ever remain clear and distinct between the ancient deposits and the modern ones, not only in the fossils themselves, but in the texture of the beds. For all modern deposits made by rivers and streams, even when these empty into the ocean or other large body of water, are made up of *mixed particles,* constituting a more or less heterogeneous mixture of materials; in contrast with which we have prodigious deposits in every part of the world, belonging to the Paleozoic and the Mesozoic formations, which are astonishingly uniform in texture throughout hundreds of feet in thickness and often extending over hundreds or even thousands of square miles in area.

Contrasts. Let us now briefly review the facts regarding the condition in which the fossils themselves are found.

1. First we may consider the *relative abundance* of fossils in the ancient deposits, as compared with the modern.

We have already seen that the modern fossiliferous deposits are scanty, and the specimens themselves very imperfectly preserved. The arctic explorers have remarked with amazement on the scarcity of modern organic remains in the arctic, where such a profusion of animal life now exists; declaring that it is far easier to find the remains of some Mesozoic or Tertiary monster in the rocks than it is to find the carcass of a modern animal. Then, too, dredgings about the mouths of such rivers as the Thames and the Hudson have shown the entire absence of such remains of land animals as we might expect to find there,

in view of the numbers of domestic animals which live along the banks of these rivers, and which must occasionally be carried downstream. Vertebrate fish also are very rarely found in modern deposits, for they require "speedy burial after death" (Dana) to escape destruction from decomposition, as well as from animals which would eat them up.

It has been claimed that a violent mixing of cold waters with warm ocean currents, such as takes place occasionally in heavy storms, will kill great quantities of fish; and that great numbers are also killed by being driven from salt water into fresh, or *vice versa.* These phenomena do occur; but in all such cases, the fish rise to the surface and float away to the shore, or to the open ocean, to be devoured bit by bit by all sorts of other animals. It is doubtful if a single specimen out of such great shoals as are sometimes thus destroyed, ever *is buried* in sediments in such shape as to make possible its identification after a year has elapsed.

In very notable contrast with these modern conditions are the fossil fishes found in many of the ancient deposits; for here we find them *entombed in whole shoals,* constituting beds many feet in thickness and sometimes extending miles in area, the fish often so close together as to touch one another, and all so astonishingly preserved that we can make out the full outline and often many of the delicate tissues. Where, for instance, in our modern world, do we have anything going on similar to the record that is preserved for us in the great fish beds at Lompoc, California, at Fossil, Arizona, or in the Onondaga limestones of Ohio and Michigan? Or where is there anything to-day forming like the shales of Monte Bolca, the black slates of Glarus, the calcareous marls of Œningen on Lake Constance, the Jurassic shales of Solenhofen, or the copper slate of the Mansfield district,— to mention a few more localities from Europe? The list might be continued indefinitely from almost all parts of the world.

In many other instances, where the remains of fish are not thus packed in on top of one another, the shales are so saturated with organic oil that they will burn almost like coal. In many of the Devonian rocks, the remains of fish "are often found in masses, as if they had been suddenly entombed in living shoals by the sediment which now contains them." (David Page.) Describing the rocks of this system in Scotland, where they cover a large part of the country, Hugh Miller remarks with amazement that "conjecture lacks footing in grappling with the enigma" as to how the "innumerable existences of an area per-

haps ten thousand square miles in extent" could be "annihilated at once," as they evidently were, for they seem to have been buried alive, though the water was evidently deep and comparatively undisturbed.

We have not the space to speak of the abundant remains of amphibians and reptiles, which have been found in myriads in many localities, packed together as if in natural graveyards. Many kinds of the larger mammals occur in similar abundance in various parts of the globe. For instance, the remains of the mammoth are found in such profusion in different parts of Northern Siberia that the soil "is said to consist only of sand and ice with such quantities of mammoth bones as almost to comprise its chief substance." (Lydekker.) In some of the warmer parts of the same country, and also in Alaska, the black carbonaceous soil, when freshly opened, has the rank, strong smell characteristic of a disturbed grave. We have already spoken of the prodigious quantities of hippopotamus bones found in Sicily, twenty tons having been shipped from one spot within six weeks, the bones being in such excellent preservation that they were used to furnish animal charcoal for the sugar factories. Mention also has been made, in a previous chapter, of the great masses of bones at La Brea, California, and in numerous localities in the Rocky Mountain region, very different from anything being made to-day, for, as Dana says, they "have been found to be literally Tertiary burial grounds."

Wonderfully Preserved. 2. But the marvelous *preservation* of these fossils is equally strong evidence that they must have perished suddenly by some tremendous catastrophe, in some wholly un-modern way.

The fishes in all the localities specified above, and of the Devonian rocks in general, are often exquisitely preserved. Some of them even show traces of color upon their skin, which is evidence "that they were entombed before decomposition of their soft parts took place." (Buckland.)

Hugh Miller's picturesque description of the condition in which, as he says, nine tenths of the fishes of the Old Red Sandstone are found, is already a classic in scientific literature, but will bear repetition in this connection:

"At this period in our history, some terrible catastrophe involved in sudden destruction the fish of an area at least a hundred miles from boundary to boundary, perhaps more. The same platform at Orkney as at Cromarty is strewed thick with remains, which exhibit, unequivocally, the marks of violent death. The figures are contorted, contracted, curved, the tail in many instances is bent round to the head; the spines stick out; the fins are spread to the full, as in fish that die in convulsions."

Of course, there are modern instances of large numbers of fish being killed at the estuaries of some rivers, and at such places as the Gulf of Kara Bugas, in the Caspian Sea; but nothing on any such scale as this. And besides — for here is the crucial difference between the ancient and the modern instances — these modern fish, after being killed, *are not buried in sediments,* and hence no such modern examples will help us the slightest in solving the problem of how the ancient deposits were produced.

Remarkable Conditions. 3. But the fossil invertebrates are often found in telltale conditions of another sort, which, however, are just as conclusive evidence of abnormal conditions' having prevailed when they were entombed.

Let us begin with the *corals.* These, we have learned, require a definite depth of water, rather shallow, but it must be clear and pure, perfectly free from any sand or other land sediments. Storms often break up the coral rock and spread out the coral mud for many miles around the reef; but such coral mud or coral sand is spread out above other layers of the same sort. In contrast with this, we often find in the ancient deposits thin beds of coral fragments repeatedly interbedded with sand and clay or even with sediments containing plant remains. Such interbedding of coral fragments is of too ordinary occurrence to require specific mention; yet I do not see that we have any modern analogies which quite explain these instances. At any rate, among the fossiliferous strata, they are of very common occurrence, so common as not to elicit any special remark on the part of writers on geology.

We do not have any *crinoidal limestones* forming at the present time, though many species of crinoids are found in various parts of the deep waters. A few live on the continental shelf, but the majority live a mile or more down in the dark, cold, silent waters. We really do not know just what were the conditions under which the ancient crinoids lived, though it is quite likely that they all lived in much deeper water than our modern corals. It is absolutely certain that the water must have been as pure as for the corals; because the crinoids must have been very susceptible to anything like strong currents, and must have been very liable to be damaged by sediments of any kind.

Yet the Lower Carboniferous limestone of both Europe and America (called *Mountain Limestone* in England), so famous for its corals and its crinoids, is constantly found interbedded with shales or sandstones, or even directly between the

coal seams themselves, as at Springfield, Illinois, and in the Lower Coal Measures of Westmoreland County, Pennsylvania. Very similar conditions, of *crinoidal remains alternating repeatedly with shales or sandstones,* are found throughout the world, wherever these rocks occur. Still I can not think that we are here dealing with any normal conditions of sedimentation.

We might speak of the vast numbers of mollusks and brachiopods; for we not only find evidence, in many instances, of their having been buried alive over vast areas, but we also constantly find species that live only in the deep, quiet waters, mingled with other species from the shore, or even with plants from the land, and always buried in sands or muds such as are never in our modern times associated with such deep-sea species as we find in these rocks.

Possibly one reason why geologists have come to view such things with complacency, under the idea that they are not at all unusual, is the fact that these conditions *are indeed the usual thing* in all the so-called "older" rocks. For throughout all the Paleozoic and the Mesozoic formations of practically the whole world, these same conditions prevail; so that, though they are certainly abnormal from the point of view of modern conditions, yet their very *universality* throughout the fossiliferous rocks has had the strange effect of making scientists perfectly accustomed to them, and by some strange freak of logic, has tricked them into calling these things the real normal conditions.

We can not do better, in closing this part of our subject, than to give the words of De la Beche, the first director of the British Geological Survey, who wrote his "Geological Researches" before the uniformitarianism of Lyell had cast its hypnotic spell over scientific research. De la Beche is very positive in teaching the general doctrine that most of the fossils were buried suddenly and in an abnormal manner. His words are, *"A very large proportion of them must have been entombed uninjured, and many alive, or if not alive, at least before decomposition ensued."* (P. 265.) And it should be particularly noted that this illustrious author is speaking, not of merely some particular instances here and there, but *of the fossiliferous deposits in general.* And these words are just as true to-day as when written, almost 90 years ago.

Surely every judicial mind that is not hampered by uniformitarian prejudices must conclude that we have, in every part of the world and in every sort of fossiliferous formation, vast numbers of fossils which, in the light of the conditions which now prevail, become eloquent protests against Lyellism, and

which constitute collectively *prima facie* evidence that our globe must at some time in the long ago have witnessed some sort of cosmic convulsion.

And there are two or three additional facts which give much more certainty to this general conclusion.

Change of Climate. 4. The next point which we ought to consider is that of *climate.* There is good evidence from the rocks, that there has been a sudden and permanent change in the climate of a large part of the earth. We may briefly review this subject of climate as revealed by geology.

Sir Henry H. Howorth, who wrote three very elaborate works against the glacial theory, gives us some remarks about the relative value of the various kinds of evidence bearing upon this subject of climate. He says that the flora and fauna are virtually the only thermometer with which we can test the climate of any past period. "Other evidence," he says, "is always sophisticated by the fact that we may be attributing to climate what is due to other causes; bowlders can be rolled by the sea as well as by subglacial streams, and conglomerates can be formed by other agencies than ice. But the biological evidence is unmistakable; cold-blooded reptiles can not live in icy water; semitropical plants, or plants whose habitat is in the temperate zone, can not ripen their seeds and sow themselves under arctic conditions." ("The Glacial Nightmare," p. 427.)

And yet, when we examine the whole geological series from the Cambrian to the Pleistocene, we shall find, as A. R. Wallace well remarks, only "one uniform climatic aspect of the fossils." There is *but one climate known to the ancient fossil world,* as revealed by the plants and animals entombed in the rocks; and that climate was a mantle of springlike loveliness which seems to have prevailed continuously over the whole globe. Just how the world could have thus been warmed all over may be a matter of conjecture; that it was so warmed effectively and continuously is a matter of fact.

It would be quite useless to go through the whole fossiliferous series in order, for there is not a single system which does not have coral limestones or other evidence of a mild climate away up north, most of the systems having such rocks in the lands which skirt the very pole itself. The limestones and coal beds of the Carboniferous are the nearest known rocks to the north pole. They crop out all around the polar basin; and from the dip of the beds, they must underlie the polar sea itself. But it is needless to go through the systems one after

another, for they "uniformly testify that a warm climate has in former times prevailed over the whole globe." (A. R. Wallace.)

According to the popular doctrine of successive ages, it becomes a very interesting and a very important question to decide as to how far back in "geological time" *man* made his first appearance on earth. For a time, it was stoutly maintained, by many geologists and archæologists, that human remains had been found in deposits of the Miocene of France, even if the notorious "find" on the island of Java should not turn out to be human or should prove to be "younger" than the Miocene. Of course, there is no real scientific foundation for these chronological distinctions between the various divisions of the Tertiary and the Quaternary, even if we could admit (which the present author does not) some distinction between such great divisions as the Paleozoic, the Mesozoic, and the Tertiary (Cenozoic). But certainly the distinctions made between the subdivisions of the Tertiary deposits, or between the latest of them, the Pliocene, and the Pleistocene, are founded entirely on a theory which has no justification, even when they are not founded on the mere caprice and personal "tact" of the experts who pronounce upon them. But the evolutionary archæologists and anthropologists demanded a good long recessive vista as a background for "primitive" man; and for a time, they insisted on giving a Middle Tertiary date for the beginning of human history. More lately, however, the "Glacial Age" has been lengthened out sufficiently to suit them, and most of them are now content to bring down the dates of "paleolithic man" within the Pleistocene.

But whether or not we accept these theories about human remains' having been found in Tertiary (Miocene) strata, it becomes an interesting point to consider *what sort of climate prevailed* over the world during the time that the Miocene deposits were laid down. But the Miocene rocks are among the most abundant and the best known of any of the strata found in the arctic regions. In Greenland, Iceland, and Spitzbergen, they give us beeches, oaks, planes, poplars, walnuts, limes, magnolias, holly, logwood, hawthorn, ivy, grapevines, "and many evergreens, besides numerous conifers, among which was the *Sequoia,* allied to the gigantic *Wellingtonia* [Sequoia] of California." (James Geikie.)

I suppose that the evolutionary geologists will be shocked if we mix the magnificent Pleistocene fauna with this flora of the Miocene, although it seems perfectly evident that the plants and the animals are the *necessary complements of*

each other. But unless we outrage common sense and all human experience by placing these plants just mentioned in one age and their evidently complementary animals in an entirely different one, we shall have to declare that at this same time there roamed over England and all Western Europe, over North America and Siberia, those giants of the prime, the mastodon, the mammoth (which can not be specifically distinguished from the modern Indian elephant, *Elephas indicus*), the great lion, the Cape hyena, the rhinoceros, and the hippopotamus, while monkeys and parrots chattered in the palms and the acacias, and giant turtles and crocodiles bathed in the tepid waters.

But suddenly an awful change took place. The exact details of how it occurred may still be somewhat uncertain; but that it was astonishingly *sudden,* and that it must have been a change affecting *the entire world,* seems as certain as man's own existence. As a well-known geologist remarks, this genial climate in which these animals lived "was *abruptly* terminated. For carcasses of the Siberian elephants were frozen so suddenly and so completely at the change, that the flesh has remained untainted." (Dana.) And this author emphasized the word "abruptly," as I have done.

In concluding this topic of climate, we need only summarize by saying that the fossils, both of plants and of animals, uniformly and with absolute consistency, testify that a surprisingly mild and uniform climate prevailed over the entire globe while these plants and animals were living. If we disregard the fanciful speculations based on the striated rocks, the traveled bowlders, and other related phenomena, which at the very most are ambiguous in their testimony, and if we listen to the unequivocal testimony of tropical plants and animals found away to the north and even within the arctic regions, we must declare that *geology knows only one climate* until this sudden change came; and this astonishing climate seems to have been practically uniform over the entire globe. This sudden and world-wide change of climate is somehow intimately connected with the geological exchange of land and water and the formation of we know not how much of the geological deposits, and serves to mark, in the words of Howorth, the "great dividing line" between that old world, with its perpetual summer, and our present world, with its terrific extremes of heat and cold.

This radical and world-wide change of climate, therefore, demands ample consideration when we seek to frame a true and scientific induction as to how the geological changes took place. That it was no secular or gradual affair, but that the

climate "became *suddenly* extreme, as of a single winter's night" (Dana, "Manual," p. 1007), the Siberian elephant "mummies" are unanswerable arguments, and arguments whose true meaning can not be misunderstood. That this change occurred within the human epoch is conceded by every scientist.

Degeneracy. 5. Very closely associated with this matter of a change of climate, though probably also dependent partly upon other causes, is the great principle that, regarded as a whole, the fossils of both plants and animals are *usually larger and more thrifty-looking* than their corresponding modern representatives.

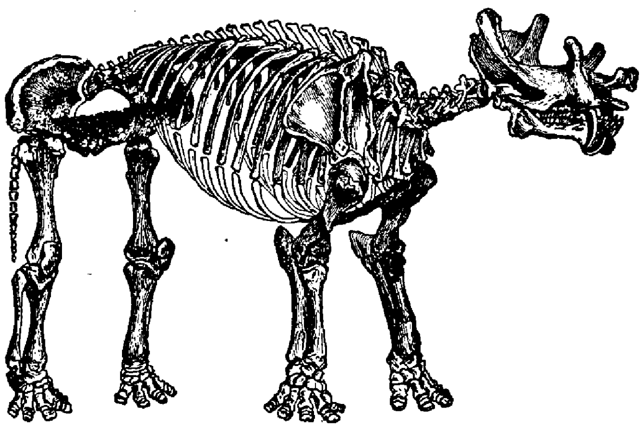


FIG. 440 A huge Eocene mammal (*Tinoceras ingens*), which is probably identical with the genera named *Dinoceras* and *Uintatherium*. It is also called *Eobasileus*, and a few other names. (After Beddard.)

There are a few exceptions; the modern squids seem to be larger than any hitherto found fossil; there are no large fossil anthropoid apes; we have several types of trees growing in California and in Australia which are decidedly larger than any similar kinds (*Sequoia* and *Eucalyptus*) found in the fossil state, or indeed than any other fossil trees whatever. There may be a few other exceptions to the rule just stated. But whether we take the insects, the crustaceans, the brachiopods, the mollusks, the amphibians, the reptiles, or the mammals, or even if we consider any single *order* or *family* or *genus* which has living representatives, the exceptions to this general rule, if there are any, are so few and so unimportant as to be quite negligible.

Even when the fossil species are proved to be identical with the living ones, as has now, after long wrangling, been re-

luctantly conceded in the cases of the mammoth, *Hippopotamus major,* and the "cave" forms of the lion, bear, and other characteristic Pleistocene mammals, the strikingly larger dimensions of the fossil forms are recognized by almost every schoolboy who has visited any of our larger museums. To quote the words of John Allen Howe, of the British Museum: *"Elephas antiquus,* for instance, attained a more excessive bulk than any other proboscidian either before or since, the woolly rhinoceros, the great hippopotamus, the cave bear, cave lion, and giant deer were all larger than their living representatives." ("Encyclopædia Britannica," Art. "Pleistocene.")

But the point which needs to be noted in this connection is not the mere difference in size between the fossils and the moderns. The fact which is of especial significance for our purpose, as helping us to understand the true nature of the geological changes, is that this peculiarity of large size is *characteristic of all the fossils,* taken as a whole; and that when we cross over into our modern world, the change in the characters of the fossils is *just as sudden and just as noticeable as is the change in climate.* Practically all our modern animals and plants, whether terrestrial or marine, are degenerate dwarfs. Variation there is and has been; in many instances, by careful breeding and cultivation, man has been able largely to overcome this almost universal tendency toward degeneration. But with one voice do the rocks testify that the general trend of variation has been downward and not upward. We may even state as a great biological law, a law incomparably more important and more securely established in actual fact than many generalizations put forward in the past by such men as Haeckel, Agassiz, and others, that *degeneration has marked the history of every form of life of which we have knowledge for a time sufficiently long to judge concerning the matter.* And it is of the utmost geological importance to note that this very abrupt change in the size and character of the fossils coincides exactly with the great dividing line between the ancient and the modern world.

Changes of Land and Water. 6. It is scarcely necessary to formulate as a separate fact the general principle that *great transgressions of the ocean* have been the cause of the formation of immense rock deposits in every part of the world, in which the remains of thousands of living species of plants and animals (perhaps of man himself) were entombed. And they are the splendidly developed forms of that old world of ideal climate which we find thus buried by flowing water, in many

cases evidently ocean water, where now the land is high and dry. The total of the geological facts is merely a cumulative argument proving this most conclusively.

> "O earth, what changes hast thou seen!
> There, where the long street roars, hath been
> The stillness of the central sea."

But the meaning of this great general fact will be entirely lost to us, if we do not continually remember that, while these changes took place a long time ago, it is with unmistakable fossils *of forms living in our modern world* that we are here dealing; and if we do not also remember the great principle already emphasized in the previous pages, that it is only an artificial and a highly theoretical distinction that can be made between the times of deposit of the various water-formed rocks found all over the globe. Of course, these rocks were not all laid down at once. In any particular locality, the lower strata were obviously laid down before the upper, it may have been a considerable length of time before. But the methods hitherto in vogue for reading the length of time involved, have been proved to be wholly unscientific and unreliable. Whether we shall ever be able to solve this part of our riddle, is a question for the future; it certainly has not been solved, except in the most grotesque way, hitherto. But the great general fact is that *we have a whole fossil world on our hands,* buried by moving water; and this is the one prime and essential fact with which we have to deal in interpreting the long-past history of our globe.

Mountain Making. 7. The last great phenomenon with which we shall deal in this series is that of *mountain making.* It is the strata formed by moving water, which contain the remains of these thousands of living plants and animals, that now constitute many of our greatest mountain ranges in all parts of the world. This, then, is another most important event which has taken place *since man and these myriad plants and animals appeared on earth;* and this event likewise needs ample and careful consideration, when an attempt is made to frame any general induction as to how the great geological changes were caused and when they occurred.

We have seen how evolutionary geologists date the making of the various mountain ranges. Evidently a mountain could not be formed until after the strata composing it were laid down by the water. For example, if Eocene strata are found anywhere on the top or on the flanks of a mountain range, the

making of this mountain must be postponed until after the Eocene "period," much as the evolutionists would like to have this mountain making out of the way as early as possible on the geological program. Unfortunately, however, almost all the mountains contain strata so very astonishingly "young" that practically all of the mountain making of the world must be postponed until almost the very close of the entire program, and then *all take place practically at once!* This is a very awkward situation, to be sure; but it can not well be helped. I can not find any very recent textbook of geology which has practically anything to say on this matter; it is a most embarrassing subject.

All of the Pacific coast ranges of North America, with most of the whole American Cordillera, from Cape Horn to Alaska, contain "late" Tertiary strata; and hence their lifting from the sea level has to be put off until the close of the Miocene, or in some localities, till the close of the Pliocene,— unless huge fresh-water lakes can be imagined to have formed these beds. The Andes, with at least half of South America, are also of very late date, as are also the Pyrenees, the Apennines, the Carpathians, and, indeed, the larger part of Southern Europe, with large undefined parts of Africa and Australia.

As for Asia, the most recent investigators of the geology of that continent declare that the mountain ranges throughout much of Asia *"challenge credulity by the evidence of their extreme youth"* (Bailey Willis, "Research in China," Vol. 2, p. 24), declaring the opinion that "the principal continental upwarp of Central Asia" must have occurred even after all of the Tertiary "period." "It appears to fall chiefly within the Quaternary." (P. 99.) Other geologists had already admitted the "late" Tertiary date of the Himalayas; but in view of the recent evidence of the extreme youth of the rest of the mountains of Asia, Willis suggests that possibly these, the greatest mountains of the globe, may date from the Pleistocene. (P. 96.)

Thus over all parts of the globe which have been scientifically examined, the uplifting of the mountains has been *practically one event,* even though the evolutionists have every need to have this mountain making take place gradually, on the installment plan. Evidently this work of mountain making throughout the earth may not have occurred until *all* of the real fossiliferous strata were deposited, and then may have been all crowded into a very short period of time. Certain it is that the whole of this work must have taken place since man and the other thousands of living species were on the earth; for these mountains *contain their fossils by the myriads,* these fossils

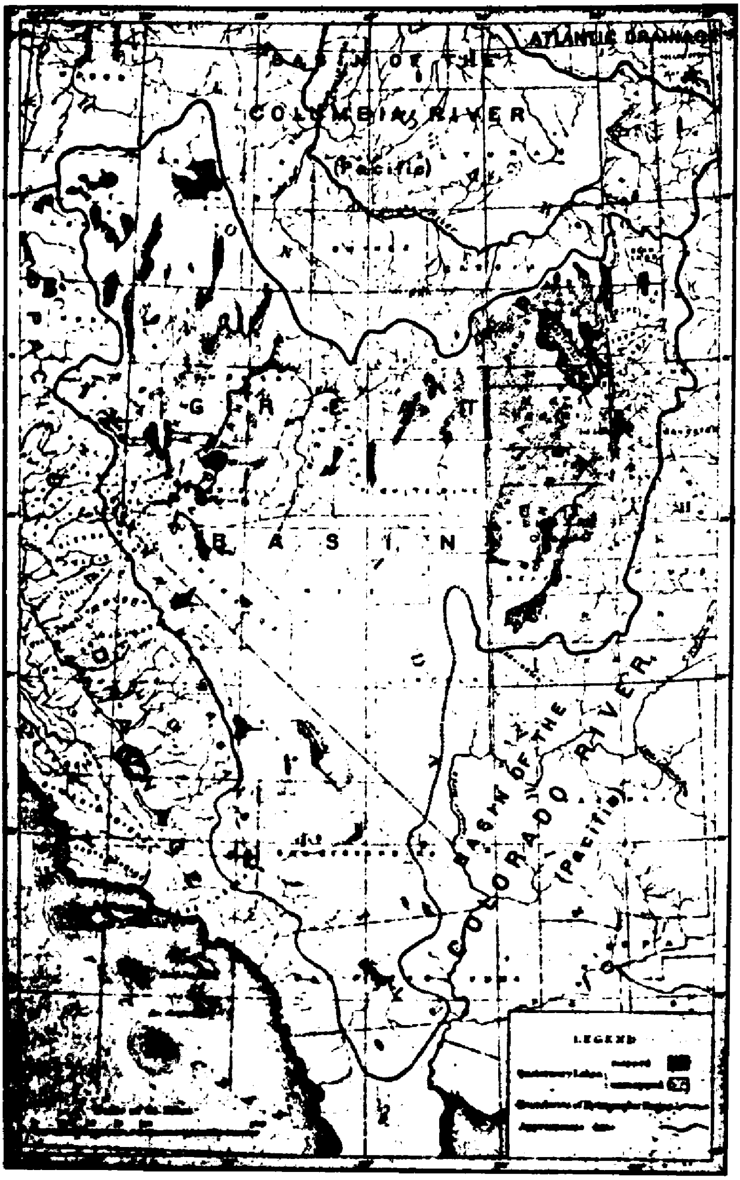


Fig. 441. The Great Basin of Western North America. (U. S. G. S.)

having been buried by flowing water, in most cases demonstrably ocean water. No wonder Dana says that this late date of the mountains is "one of the most marvelous in geological history." ("Manual," p. 392.) And he adds, "It has been

thought incredible that the orographic climax should have come so near the end of geological time; . . . yet the fact is beyond question." (P. 1020.)

All of this agrees perfectly with the hypothesis which we have been considering. On this basis, the mountain making of the entire world (except in the case of some few mountains composed of Archæan rocks) was *practically one event*, begun only after the deposition of most or possibly all of the fossiliferous strata, and completed rapidly, long before the beginning of scientific observations. Certainly nothing like the birth or even the gradual growth of a mountain range has been observed since the beginnings of human records.

What Do These Things Mean? We have enumerated *seven* large outstanding facts regarding the fossiliferous rocks. *What do these things mean?* They are all consistent with one another, and together they constitute a cumulative argument of some sort; and any truly rational and scientific induction regarding the causes of the geological changes must take them all into consideration, and must agree with each one *singly*, and must also agree with them *all collectively*. I do not know of any other way of establishing a really scientific induction regarding the great outstanding problem of geology. All conclusions on this general problem of the causes and the manner of the geological changes, which do not take these great facts into consideration, are mere snap judgments, blind guesses, or puerile speculations, and can have no scientific value. On the other hand, even the most faulty and inadequate conclusion which *attempts* to embrace all of these facts, must have some scientific value, although it may require even more data than we now possess to work out a detailed picture of what is called for in this general conclusion.

Many of these seven facts are really new discoveries within recent years, and were wholly unknown to the pioneers of the science. Others have been known in a sort of way for many years, but were misunderstood or obscured by the prevailing theories. But we now have all these facts before us; and on a correct understanding and interpretation of these facts rests the future of the science of geology, so far as the latter ceases to be a cosmological speculation, and becomes inductive in its methods.

But the further consideration of these matters must be left over for another chapter.

CHAPTER XL

Scientific Methods

Facts and Theories. Science consists of two essentially distinct parts, facts and conclusions. Not that we can always succeed in keeping them distinct; but we attain to clearness of mind and approach scientific certainty, just in proportion as we approximate to this segregation of facts from conclusions. For the two are essentially distinct in their natures. Facts are the raw materials with which science works. They are the bricks; but bricks alone, without organization, will never make a house. The cement between the bricks may be spoken of as corresponding to conclusions or theories; while the method of arranging the bricks together so as to constitute a structure, makes the whole thing into an organized mass — otherwise, into a science. No amount of mere facts alone can make a science; the facts must be brought into right relationship to one another. That is, the facts must be *explained by some conclusion,* this explanation being technically a theory, an induction, or a generalization from the facts under consideration.

Thus conclusions formed from any two or more facts so as to "explain" them, or so as to put them in right relation to each other and to still other facts, become theories; and there can be no organization of facts, or in other words, no science, without many theories.

The Danger of Hypotheses. But theories are of no value unless they are to be *used;* and any theoretical "explanation" of certain facts, when used to help explain other facts, becomes a *hypothesis.* That is, *a theory put to work is a hypothesis.* And hypotheses are always dangerous things. We put our intellectual freedom at stake whenever we adopt a hypothesis. We can make absolutely no progress in any line of science without using them; yet they are more dangerous to use than dynamite. And the more we use a hypothesis, and the more plausible it appears because of the ease with which it seems to help us explain other facts, the more surely do we become its slaves, and the more hopeless becomes our intellectual slavery, *if* this hypothesis happens to be *really wrong;* for a cherished hypothesis blinds the eyes of the observer to new facts, just as a gift has been said to blind the eyes of a judge in court. We never persevere in making experiments to test out a hypothesis in which we really believe; and often we will not listen to the

testimony of others who claim to have tested it, if their results do not tally with what our pet hypothesis has taught us.

Werner's Method. A good geological example of how this principle works out, is that of Werner and his disciples. The great Neptunist had acquired a degree of skill in identifying the various minerals with which he had to deal, and he taught his pupils that the schists, limestones, sandstones, etc., always occurred in a definite sequence. And as these pupils trained under his hypothesis went from Werner's narrow little district of Germany over the rest of the world, through Western and Southern Europe, or through North America, or Mexico, or Central America, they always seemed to find the rocks occurring very much as their master had taught them to expect. Even the scholarly and keen-eyed Von Humboldt, in his epoch-making trip through Central and South America, thought that the rocks which he saw confirmed Werner's chronological arrangement, and he wrote his voluminous books accordingly.

But examples of strata plainly contradicting Werner's theory or hypothesis finally accumulated in such enormous numbers as to put a stop to this solemn scientific farce, by convincing some who were not slaves to this hypothesis, that Werner's onion coats must be a mistake. Yet such was the implicit trust reposed in this accepted hypothesis, that real intellectual courage was required to break away from it — a real intellectual revolt. But finally some brave souls gathered the courage to declare that this expert mineralogist, who nevertheless had never in his life been outside of his little district around the Erz Mountains in Saxony and Bohemia, had after all not been gifted with any supernatural knowledge of just how the rocks would always be found to occur on the other side of the globe. And they said that this venerable onion-coat hypothesis should not any longer domineer over geological thinking, when there were actual facts which plainly contradicted it. For facts should always have the right of way over theories and hypotheses, no matter how long the latter had been accepted, and no matter how many facts they had hitherto helped to explain.

Biological Onion Coats. But a succession of certain groups of life was substituted for Werner's mineral onion-coat theory, this new theory being based now on biology instead of on mineralogy, but being now *a biological onion-coat theory,* instead of a mineralogical one. And if I can understand the matter correctly, we are now about in the Von Humboldt stage of this biological theory. We already have a large accumulation of facts contradicting it; but through reverence for illustrious

names, or through intellectual slavery to hypothesis, geologists have merely stared in open-eyed wonder at the accumulating examples of what they call *"deceptive conformity,"* and have invented huge overturned folds or *"thrust faults,"* involving

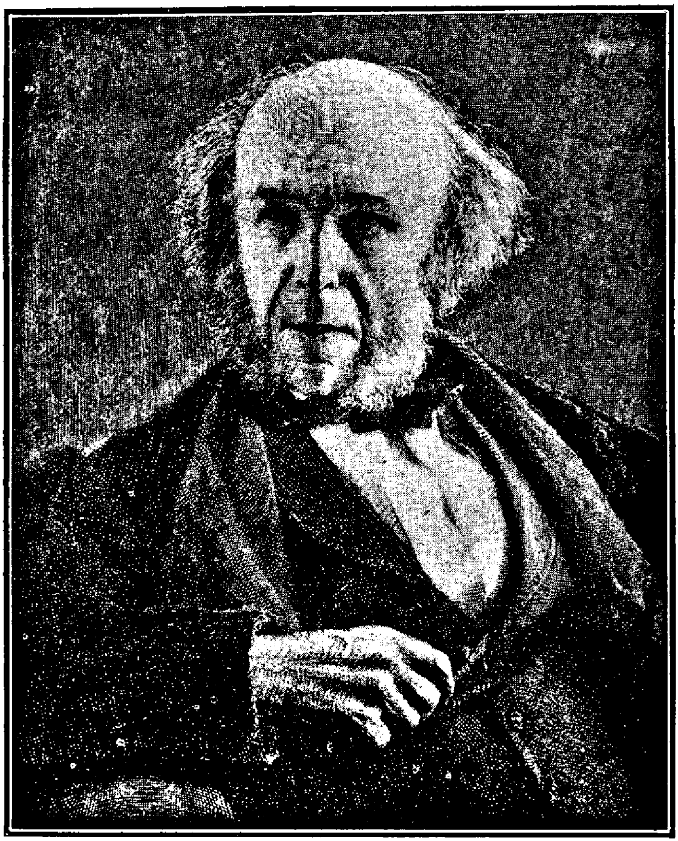


FIG. 442. Herbert Spencer (1820-1903), one of the first teachers of the theory of evolution.

thousands of square miles of area, rather than doubt the perfect sufficiency of their theory.

This hypothesis of a succession of plants and animals has been with us for a long time; but historically and logically it has no foundation whatever, except that William Smith and Cuvier and others in the early part of the nineteenth century found the fossils occurring in a certain order of relative sequence in England and France, and concluded that this was

a better method of identifying the rocks than Werner's methods, which were then falling into disrepute.

However, Herbert Spencer tells us that the "original nomenclature of periods and formations" brought over from Werner, long kept alive the original idea of complete envelopes encircling the whole globe like the coats of an onion; so that now, instead of Werner's successive ages of limestone making and sandstone making, and successive suites of these rocks, we have, says Spencer, successive ages of various types of life, with successive systems or "groups of formations which everywhere succeed each other in a given order, and are severally everywhere of the same age. Though it may not be asserted that these successive systems are *universal,* yet it seems to be tacitly assumed that they are so. . . . Though probably no competent geologist would contend that the European classification of strata is applicable to the globe as a whole, yet most, if not all geologists, write as though it were so." ("Illustrations of Universal Progress," pp. 329-380; edition of 1890.)

And he adds this pointed question: "Must we not say that though the onion-coat hypothesis is dead, its spirit is traceable, under a transcendental form, even in the conclusions of its antagonists?"

But what progress can we point to in the theoretical aspects of our science, when we find that these words are *just as true to-day* as when first written, nearly three quarters of a century ago?

Warnings. Of course, no geologist of to-day would care to be caught openly defending the onion-coat theory even in what Spencer calls its "transcendental form." But the only way in which to put in an honest disclaimer is to say with Huxley, "All that geology can prove is local order of succession." ("Discourses Biological and Geological," pp. 279-288.) And we should not only repeat these words, but we should let them become a part of our being; because, as this clear thinker pointed out, "the moment the geologist has to deal with large areas," there is incalculable mischief in projecting this local order of succession into distant localities, and saying (as all geologists continue to say) that these widely separated strata *are* or are *not* of the *same age;* for of this "there is not a shadow of proof," as Huxley very candidly admits.

Such language sounds very strange to us to-day, as do also the following truthful words from the same author:

"In the present state of our knowledge and of our methods [*sic*], one verdict—'Not proven and not provable'—must be

recorded against all grand hypotheses of the paleontologist respecting the general succession of life on the globe."

These words have been assented to and praised in a general way, but they have never had the slightest effect in changing

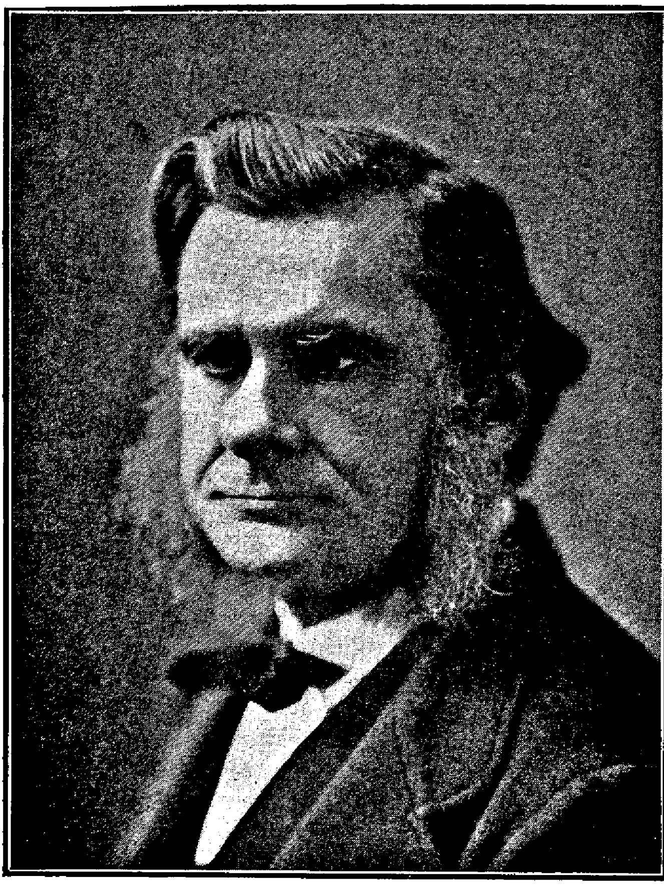


FIG. 443. Thomas Henry Huxley (1825-1895), ardent advocate of the theory of organic evolution.

the methods or the theories of geologists; for geologists would never go to such absurd lengths to explain away the plainest evidence of our eyesight and our common sense, as they do in the invention of so many instances of "deceptive conformity" and "thrust faults," if they felt that there were any of their colleagues who had any suspicion about the European classification's being "applicable to the globe as a whole," or who had

any latent prejudices about their science's being unable to prove any more than "local order of succession." And finally we should never have had so much discussion within recent years about positive and negative "eustatic movements," if many geologists had not like Professor Suess been astonished in finding that even the more minute subdivisions of the scale invented in Europe had been found to "extend over the whole globe."

I have already pointed out that the reason why this stratigraphic scale can be applied to the world at large, is that it is merely a *taxonomic scale*, purely arbitrary and artificial, but applicable everywhere, because *a taxonomic series is applicable everywhere.* But certainly the mere stratigraphic sequence found in Europe is not applicable to the world as a whole, or we should never have had to invent the terms "deceptive conformity" and "thrust faults."

Absurd Methods. But is there anything more pathetic than the absurd methods constantly employed to interpret all our new discoveries in terms of the biological onion-coat theory of William Smith and Cuvier?

Notice the method of reasoning employed. We first take the order found in a few corners of Western Europe as the gauge, the standard, for all the rest of the world. Then when we find great masses of mountains extending over nearly a whole State which are at variance with our rule, even though the rocks appear to be in a normal order, and though the line between the upper beds and the lower ones "acts exactly like the line of contact between two nearly horizontal formations," and in a clear section cut out by a river the two "appear to succeed one another conformably" (McConnell), yet we are in such utter slavery to our hypothesis that we are prepared courageously to deny every objective evidence of our eyesight and all the physical facts, in order not to throw discredit upon our time-honored hypothesis. Solely because of our intellectual bondage to a theory invented to explain the local fortuitous order observed in a little corner of Europe, we are here bidden to deny the plain evidence of our senses, because these rocks do not happen to be in the order predicted by our theory. And this is being done, not in the name of scholastic word-twisting in the tenth century, but in the name of Baconian science in the third decade of the twentieth century. And if there is any more pathetic example of slavery to a hypothesis, I have failed to find it through the whole history of inductive science.

There is only one possible argument in favor of this geological series' actually representing a true historical order, and that

is the mere rule-of-thumb argument that we *usually* find the fossils occurring in this order of relative sequence, and we *assume that this order can never be reversed.* There is no other possible argument from stratigraphy alone. But utterly oblivious of the purely artificial way in which geologists have had to piece together these various standard formations from many scattered localities all over the globe in order to make the geological series complete, the experts in the science continue to have such faith in this "normal" sequence, that, in such an example as that in Montana and Alberta, they tell us with a sober face that a country nearly 20,000 square miles in area was elevated perhaps some 20,000 or 30,000 feet and pushed bodily over on top of the soft Cretaceous shales for 30 miles or so; then they tell us that the upper 18,000 or 25,000 feet conveniently disappeared by erosion, leaving only the lower beds of this great thrust mass. But these now lie in such a remarkable semblance of natural conformity as to excite the amazement of the most experienced observers. Surely a case of being hypnotized by a cherished hypothesis into blind and unquestioning obedience to its necessities!

How much of the earth's crust would we have to find in this upside-down order, before it would be permissible for us to question this "standard" or "normal" order of the fossils, which was started in England and France and Germany, and which we have pieced together and completed by a purely artificial method from every part of the globe? It would really seem that any amount of the earth's surface might be found in this condition, without seriously disturbing the sublime confidence which modern geologists still repose in a hypothesis which has been so long employed.

But I fancy that some people will think it perfectly axiomatic and requiring no proof, that the lower and more generalized forms of life must have come into existence long before the higher or more specialized. Though seldom formally expressed, this idea seems to be heard as an undertone through all discussions of these subjects. But is such a postulate sufficiently axiomatic, so self-evident a truth, as to be a sure foundation stone not only for geology but for all biological science? *Why must we always treat stratigraphic geology as a cosmogony?* Obviously this attitude begs the whole question in dispute between evolution and creation, and thus removes these purely stratigraphical questions completely from the court of objective fact, and allows them to be decided by intuition and mere subjective impressions. What is the use of pretending

that we are investigating a problem of natural science, *if we already know beforehand that the lower and more generalized forms of animals and plants came into existence first, and the higher and more specialized came only long afterwards,* and that specimens of all these successive types have been pigeonholed in the rocks in order to help us to illustrate this wonderful truth?

Not the Only Interpretation. Let us come back to earth, and try to confine ourselves to questions of objective fact and to scientific methods, leaving questions of metaphysics and intuition to others. Human beings have always had plenty of axiomatic notions, plenty of *a priori* postulates; and the history of natural science is one long record of an unending struggle with just such ideas, and with a weak tendency to inject these methods constantly into scientific investigations. This evolutionary doctrine is indeed allowable as a hypothesis, a mere working hypothesis,— though I fancy that it has been considerably overworked during the last half century. But we must ever bear in mind that this intuition about the order in which life has occurred on the globe is *not the sole and only possible interpretation of the phenomena* with which we are dealing. There is at least *one other view* of the matter; and the evolutionist has no right to boast that his is the only possible view, until this other alternative has at least had a candid consideration. And I feel sure that we shall be doing a distinct benefit for scientific thinking, if we can frame a rational explanation of these phenomena in Western Montana and Southern Alberta, and not have to entangle our explanation with any cosmological speculations whatever.

An Illustration. Let us get at the matter by a very simple illustration.

Let us suppose that William Smith and Georges Chrétien Cuvier had been born on the western prairies of North America. Yes; and let us include along with them Adam Sedgwick and Roderick Murchison. As they grew up to manhood, they became familiar with the country around them, examining the rocks as well as the living plants and animals. And let us suppose also that these young men have become familiar with the forms of the living plants and animals in the deep seas as well as on the lands in other parts of the globe, so that they can come to the study of the rocks here near their homes without being hampered by those preconceived prejudices about "extinct species" and catastrophism which we know warped their investigations in actual life.

In due course of time, these young gentlemen become acquainted with this great "faulted" area in Alberta and Montana. They find Algonkian, Cambrian, and in some instances other Paleozoic rocks extending in what evidently was a great *continuous sheet* (now reduced to disconnected patches in many places) spread out over some 20,000 square miles, and constituting the great dominant and characteristic topographic features of Northwestern Montana and Southern Alberta. But everywhere the underlying beds are Cretaceous; yet these four young investigators, who come to these studies without any theoretical prejudices, have had no warning that the rocks are not in a perfectly "normal" order.

We will suppose that these four young friends are of a philosophic turn of mind, wishing to get at the real heart of things, but more cautious than we know some of them to have been in real life. But they are determined to know what these things mean, how these strata got here, and what these rocks have to teach us regarding the history of the world and the origin of things.

The Three Interpretations. With these geological phenomena before them as a basis of thinking and reasoning, it is quite evident that these young gentlemen might have their choice of *three* possible interpretations. On some minor points, there are other possible variations of these typical explanations; for it is confessedly a complex and intricate subject. But the three explanations here presented are the three which *have been adopted* at various times, as shown by the history of the science.

I. They might say: These strata represent successive ages that formerly prevailed over the globe; and they show that the earth has experienced great vicissitudes. We might think, as some do, that we see here no sign of a beginning, no prospect of an end. But it is more probable that we have here a record of *successive creations and catastrophes,* one set having been destroyed by some great catastrophe before the next set of animals and plants appeared. And if we should examine the rocks of all the rest of the globe, we should have an exact chart of these successive creations and catastrophes, coming down to our own modern conditions.

II. Or they might say: These strata represent successive ages, and each set of rocks containing a particular group of animals and plants was undoubtedly spread universally around the globe in the first place, or when formed, though now extensively interrupted by erosion or hidden from view by other strata. But these successive ages can be accurately determined by the

fossils contained in these rocks, and can thus be identified wherever found. And the *order here observed is to be taken as the actual order* in which these successive assemblages of life prevailed over the earth. However, there is no reason to suppose that anything like a catastrophe marked the change from one set of conditions to the next. Here the change may seem abrupt; but elsewhere we should find evidences of a *gradual transition* from the one set of conditions to the next, for all the changes of the past must have been brought about by *gradual, everyday causes,* such as are now going on.

III. Or they might say: These strata are mere *local phenomena,* and could never have been continuous around the earth like onion coats. Elsewhere we should probably find the various groups of fossils in very different relative orders; for these beds are of merely limited horizontal extent. They are *mere local faunas and floras,* buried at some time or times; though we do not have here sufficient data to determine either the when or the how. Any general theory regarding the causes of these changes can be determined only after the most painstaking and exhaustive study of the rocks of the entire globe. A local catastrophe of some sort may seem to be indicated here by these local conditions; and if similar conditions should be found to occur over the entire earth, we might have to believe that a great world catastrophe has occurred. But in the strata here alone, we do not have sufficient data to form a safe and intelligent opinion. Sherlock Holmes might diagnose a disease by a mere glance at his patient's boots; but even this glance might furnish the great detective with more pertinent data than we have here in this limited locality for framing a general theory of the geological causes and processes applicable to the whole world.

The Application. But it is evident that the *second* of these theories is just as unscientific and absurd as the first, possibly more so. Even the evolutionists own that it would be manifest folly to take the relative order of the fossils in Alberta and Montana as the standard for the rest of the world. Yet such an action is scientifically and philosophically *no more absurd than the methods now in vogue.* A standard order compiled from these localities might not survive as a measuring rod for the rest of the world *quite* as long as one from England or France or Germany, for we should probably very soon recognize its palpable disagreement with the order of the rocks found elsewhere; but theoretically it ought to make just as good a standard order as the one under which we are now working. Also,

this area is about as large as that from which the present standard order of the rocks was first worked out by Smith and Cuvier.

Accordingly, we may conclude that the *third* of the explanations suggested above is the only one left available for us in modern times who wish to build safely on a sure basis of fact.

Historically, then, we have abandoned the first of these theories, and are in the *second stage* of the development of a true geological theory. We have not exactly entered the *third* stage, but it lies just ahead. It is the geological theory of to-morrow, and of the reformed science of geology. We abandoned the first long ago, and we profess very loudly that we have left behind all the dogmatic assumptions of the second; for all geologists are very much ashamed of the onion-coat theory. But the reproach of this theory, in what Spencer so fittingly calls its "transcendental form," will still cling to our science, like a poisoned Nessus' shirt, just so long as we persist in setting up the fortuitous order of the rocks in England and France and New York State as the norm, the fixed standard, by which to measure the rocks elsewhere, and so long as we insult our eyesight and our common sense, in the presence of such "exceptions" to our standard order as we find in Alberta and Montana, by positing incredible contortions and convulsions of nature in order to make these reluctant phenomena conform to our Procrustean rule.

How long is it going to take us to be graduated out of the *second* and into the *third* and final stage of geological theory? Why may we not admit forthwith that these conditions in the Rockies are just as rational a measure to which to compel the strata elsewhere to conform, as anything in Western Europe? If they are not, why not? Why should we not discard methods and assumptions so manifestly unscientific, and start out on a new chapter in the history of this science, where facts will always have the right of way over theories, and where we can even be content to hold our restive imaginations severely in leash until we have a reasonable amount of data on which to build a safe general induction? To appropriate the words of Sir Henry Howorth, I do not know of anything to hinder such a consummation most devoutly to be wished, save "the almost pathetic devotion of a large school of thinkers to the religion founded by Hutton, whose high priest was Lyell, and which in essence is based on *a priori* arguments like those which dominated medieval scholasticism and made it so barren." ("Glacial Nightmare," Preface, pp. 21, 22.)

Other Considerations. Some geologists have sought to evade the charge that the popular geological chronology is based entirely upon the hypothetical succession of life; and they have appealed to several other methods which they say are able to supplement this succession of life, or even to establish the geological chronology on an independent basis apart from this succession of the fossil forms. A brief consideration of these other methods of correlating the strata and arranging them in an alleged "historical order" must now be given.

1. The order of *superposition.* Of course, the lower of a pair of undisturbed beds must be the older. But how much older? If the two beds are conformable and of much the same lithological texture, the plain inference is that the two beds must have followed one another in quick succession. An interval there must have been, or we should have had one bed, not two. This interval may be measured in minutes or hours, but plainly not in ages or years, probably not even in months or days. If the lower is of a very different lithological composition, the interval may have been longer; but how much longer? Might it not have been only a few hours, or a few days at the most?

If there is an *angular unconformity* between the two beds, evolutionary geology says that the lower beds must have been elevated above the sea level and eroded down to a sort of base level, then lowered into the sea — or a transgressing ocean came upon it, which is the same thing. But all this elevation, erosion, base-leveling, and resubmergence is quite gratuitous and unnecessary. It is not needed to explain an angular unconformity. Could not these strata have been eroded *beneath the sea,* if a local warping of the sea bottom had elevated one part considerably higher than the rest, and a strong tidal wave were generated by some similar disturbance elsewhere caused by some newly made prominence on the sea bottom? Surely there is no occasion to invoke an elevation above the sea and an ordinary base-leveling in order to explain an angular unconformity. Hence this angular unconformity does not at all imply (necessarily) a long lapse of time. If the beds were still unconsolidated, and a warping of the sea bottom had suddenly occurred, the upper part might be planed off by a new current of the water, and subsequently a new layer of sediment might be deposited upon it, all within the space of a few hours. Thus such an angular unconformity might represent merely the lapse of time between two successive tides.

2. *Unconformities.* Unconformities themselves are alleged to be important means of correlating distant strata. They are often spoken of as widespread, of continental or almost of world-wide extent; and they are then declared to be sufficient grounds for dividing the strata off into distinct groups, these unconformities thus marking the dividing line between distinctly different groups of fossils.

In reality, however, unconformities are *quite as local* as are the beds themselves. And such local unconformities can be correlated with other similar unconformities elsewhere *only on the fossil evidence from the beds above or below.* How then can an alleged "widespread" unconformity be used to supplement the historical succession of life? Can one lift one's self by the top of one's boots? Can a bobtail dog catch his tail by chasing it?

Diastrophism is often spoken of as a means of correlation; but it has no real existence apart from that constructive existence furnished by a combination of the ideas just considered, namely, stratigraphy, unconformity, and the alleged paleontological succession. Hence it will be useless to discuss diastrophism here as a separate subject.

3. *Paleontological breaks.* A radical change in the fossils in passing from one bed to another higher up, is always taken by evolutionary geology to prove a long lapse of time. And such a break is often spoken of as if it must prove a long lapse of time quite apart from any theory about the precise order in which the fossils are alleged to have succeeded one another. But this is by no means the case. Such a break in the fossil succession may only mean a *current from a different direction* bringing in some contemporary forms of life from a few hundred yards away, or at the most merely a few miles away. Even the most radical change in the flora or fauna may mean nothing more than this. Were there not zoölogical provinces and districts, or even narrower divisions, in the olden time? How are we going to limit the possibilities of variation in the contemporary life in geological times, except by assuming a supernatural knowledge of the past which is quite out of harmony with inductive science?

In reality, a change from Cambrian trilobites to Jurassic or Cretaceous ammonites may mean nothing more than this; that is, a change in the currents, bringing *more or less distant but strictly contemporary faunas* above one another in successive beds. There is nothing but assumption to forbid such an idea. A strictly scientific induction can not say that a long lapse of time must be represented by such a change,— from

trilobites to ammonites, or from Devonian ostracoderm fishes to Tertiary teleosts, or from Ordovician graptolites to Jurassic belemnites, or from Cretaceous dinosaurs to Pliocene mammals.

Thus even the most radical of fossil breaks can not prove any great lapse of time, nor can it assist in correlating distant deposits; for it depends for its supposed value wholly on the succession of life in a definite order, which we have insisted is only an assumption, nothing more.

4. *Paleogeography.* It has even been supposed that we can tell in which direction the land was situated relative to any particular shale or sandstone or conglomerate; and that from an elaborate study and comparison of the beds in various adjacent localities, we can reconstruct the ancient geography of land and water and ocean currents at certain periods in geological history. In this way, we are treated to a moving picture of the pulsating crust rising and falling here and there, vast transgressions of the ocean occurring from time to time and blotting out whole continents of life, and again the land emerging and being peopled by migrations from distant parts of the earth. All this is given us in the name of sober science, as if we really have a warrant in substantial fact for such a series of successive events. But it is sad to have to say that this is the most elaborate system of charlatanry, of pseudo-scientific quackery, which has been foisted upon a confiding public in several centuries.

From all this, it follows that there is no truly scientific way to reconstruct even a local chronology of the events recorded by the strata in a particular locality, except in the most general way. And whenever we attempt to compare the events of one locality with those of distant localities, or whenever we go beyond the bounds of what we can actually demonstrate by a real stratigraphical superposition of beds, we can do so only by a series of pure assumptions which are wholly unworthy of a place in a scientific textbook.

Energy Versus Time. We must next consider the old controversy of *energy versus time.* It is commonly assumed that we may explain the general geological problem either way,—by appealing either to an enormous amount of energy, or to an enormous length of time. It is assumed that energy and time are in a measure equivalent, when it comes to their usefulness in explaining geological processes. A powerful cause acting through a short period of time is assumed to be equivalent to much weaker forces acting through a proportionately long period. But it is usually declared, in this connection, that the

appeal to unlimited time is intrinsically more reasonable and more scientific than an appeal to forces greater in magnitude than those forces of which we have had contemporary experience.

But is this really correct? Is this appeal to time more scientific than the appeal to force?

On this point of energy versus time, and the rightful place which each may hold in scientific methods of reasoning, I can not do better than to quote at length from an author whose writings seem to contrast so vividly with those of many who have written upon geological subjects.

"In my view," says Howorth, "the only true philosophical method to adopt in geology, when we have a problem to explain, is to search for a competent cause in all the highways and byways of nature's arsenal. If we find any cause still operating which is competent to do the work, we shall of course accept that cause as the only one justified by the evidence. If we find a cause which is capable of producing similar effects but only on a smaller scale, we may reasonably and rightly inquire further whether the smaller cause could bear the strain of much larger demands upon it, when operating over a much longer period, and could then produce the enhanced effects. If we are satisfied that it could, we must not take it for granted that this factor of additional time is necessarily available. That is as much a question of evidence as any other problem.

"If we eventually satisfy ourselves that we can not legitimately appeal to enhanced time, or that the intensity of the force as measured by our experience is incapable of doing the work, we ought to have no hesitation whatever in appealing to a much greater force, similar in kind maybe, but greater in intensity or greater in rapidity of operation. That is surely the true inductive method. The only proviso which is a necessary element in such an appeal, is that the force we call to our aid shall be clearly and distinctly one consistent with a most rigid adherence to the laws of physics, and whose competence would be confirmed by the mathematician and the mechanic. All other appeals I deem to be transcendental, metaphysical, and outside the limits of true science, by whatsoever great men they are made; and I especially protest against the notion that geology can dispense with the methods and the results of mathematics, mechanics, and physics in framing its hypotheses.

"This, the true inductive method, I hold has been completely ignored by the geologists who, in recent years, have described the later deposits which cover the bony skeleton of the earth with their soft mantle.

"Long ago, when I was a mere boy, I was corresponding with Darwin on a subject which had always interested me, namely, how to account for the carcasses of mammoths and other beasts being preserved whole, in the frozen ground of Siberia; for the vast hecatombs of buried skeletons and bones of his contemporaries in different parts of the world; and for the great gap in the evidence and the hiatus which exists between the remains of these animals, including primitive man, and the remains of the succeeding races of men with their domesticated animals.

"Darwin, like many others who have looked the problem face to face, confessed to me that it remained to him the one stupendous mystery in the latter geological history of the world, for which no rational explanation had been forthcoming. . . .

"I hold that an appeal to limitless time is in itself as preposterous and irrational as an appeal to limitless force is deemed to be, by certain thinkers. . . . No amount of time will enable a set of human teeth to punch holes in a steel plate. Hence when we are face to face with some gigantic problem, greatly differing in degree from any similar problem at present in solution, we must not hesitate to give increased potency to our cause, in order that our induction may be sound. And for this we have surely ample justification (as I have often urged before) in some of the unmistakable monuments of nature. If we look at the placid face of the moon, where the keenest observation has failed to notice the slightest change going on at present, we find it torn and rent in a way quite unmatched by anything on the earth, and attesting a period in its history quite unlike anything at present known. If we look to our own geological record, where are we to find anything fashioned in human memory the least like the great beds of granite and gneiss, or even the tabular masses of basalt and trachyte which occur in so many latitudes, for instance in India, South America, and in Auvergne, or the quite as wonderful deposits of the chalk or the slate rocks? Can we answer our boys who ask us how these beds were formed, by pointing to any process in actual operation now, which would explain them? If we turn from these instances to those more distinctly dynamical, who is prepared to say that the riven and twisted and upheaved masses of the Himalayas and the Andes, the huge faults like that of Durham, the vast cliffs and chasms of the Alps where the Tertiary beds are thrown up on end, etc., etc., are comparable in extent and degree in any way with phenomena of which man has had direct cognizance, or which are within the capacity of any forces of which he has had direct knowledge?

"It is not only in regard to the extent of the work done that we must frequently in geology put aside any human tape measure and foot rule and appeal to a far more significant exercise of dynamical forces than can be measured by our daily experience, namely, that marked by the enhanced rapidity and actual violence demanded by the changes involved. This is true, I maintain, not merely of degree but also of rapidity or suddenness. No appeal to gradual changes will explain the vast ruins on the face of the moon, the similar ruins that cover Iceland or Auvergne, or the burnt land of Asia Minor and Lower India; the signs of violent dislocation we see in the great African rift and in the other great rifts elsewhere, and the torn and tossed masses of crystalline rocks on the Alps."—*"Ice or Water," Preface, pp. 8, 9.*

No Historical Order of the Fossils. But the appeal to unlimited time is always accompanied by the artificial arrangement of the numerous floras and faunas found in the rocks in an alleged historical or chronological order; and it is only in this connection that the idea of practically unlimited time has been built up. There would be no serious question about the length of time involved in any *single* geological event; it is only when the countless geological events all over the world are arranged in this artificial series in an *alleged historical order,* based on the fossils in the rocks, that the appeal to time has any great significance.

In a previous chapter, we have seen that this alleged historical order of the fossils is clearly a scientific blunder; for there

are many unequivocal evidences to prove that this supposedly historical order must be a mistake. There is no possible way to prove that the Cretaceous dinosaurs were not contemporary with the late Tertiary mammals; no evidence whatever that the trilobites were not living in one part of the ocean at the very same time that the ammonites and the nummulites were living in other parts of the ocean; and no proof whatever that all these marine forms were not contemporary alike with the dinosaurs and the mammals. In short, the only scientific way to look at this matter is to say that we have in the fossils merely *an older state of our world;* and the man who wishes to arrange the various burials of these animals off in some sort of chronological order will have to invent some other scheme than any hitherto considered, for all such schemes of an alleged historical order which have been hitherto proposed are now seen to be wholly unscientific.

Unity of the Fossiliferous Deposits. But there are other considerations which serve to show that the fossil world is *really a unit,* and that it is marked off or separated from our modern world in many remarkable ways. The following facts have been brought out in this connection:

1. The wholly abnormal character of many of the fossiliferous deposits.

2. The evidence of a sudden, complete, and world-wide change of climate.

3. The marked degeneration in passing from the fossil world to the modern one.

4. The fact that the upheaval of practically all the mountain ranges must have taken place since the burial of the fossils; that is, since thousands of living species of plants and animals, including man himself, came upon the earth. As a corollary from this last fact, we have the conclusion that the living plants and animals, and man himself, for that matter, must have witnessed or must have participated in most of the great geological changes — perhaps all.

All these facts tend still further to emphasize *the unity or solidarity of that ancient world.* They also tend to show how the geological changes are all connected, the fossil plants and animals being indissolubly bound together in a common fate, and how the fossil world is sharply and distinctly separated from our modern world by a very striking series of geological changes which true science can never ignore.

A True Induction. A true spirit of scientific induction must unhesitatingly face these great geological changes, and must

deal with this matter first, or before any theories can be framed regarding the early days of the earth's history. These changes in which man and the living species of plants and animals were involved *must be first explained.* Can we hope to explain these changes on the basis of any ordinary or everyday action of the elements? To ask this question is to answer it, if we have any sufficient idea of the changes here spoken of. Any comprehensive view of the radical and world-wide changes registered in the rocks must force upon us the conviction that our old world has witnessed something of the nature of *an awful aqueous convulsion.* And while it would be rash to say that all the geological changes recorded in the rocks were due to this event, yet we can make no scientific progress in attempting to unravel the events of the previous ages until we have settled the matter as to just what deposits were due to this event, and which ones probably took place in some previous age of the world's history. Certainly it may be difficult to draw the line between these two kinds of deposits; but until we have made an attempt to do this, and have succeeded in the separation of these two classes of events, we can have no right to speak of the events which may be supposed to have occurred *before* this world convulsion took place.

Here we must leave the matter for the present. We do not yet have a sufficiently accurate knowledge of all the facts to say just *how* this great geological disaster was accomplished. We can see some of the details, but not all of them. Yet the general fact of a great world convulsion through which our globe has passed, a convulsion which has registered itself in the rocks of every mountain side as well as in the strata buried deep beneath many of our most populous cities, is as certain as any other historical event — as certain as the fall of Babylon or the destruction of Carthage. And all of the sciences, such as physical geography, botany, zoölogy, and anthropology, to say nothing of geology itself, must take this great fact into account in any problem which has to do with the interpretation of present conditions and how they came about.

CHAPTER XLI

The Hypothesis of a World Catastrophe

The Two Hypotheses. Necessarily any solution which we may make of the causes of the geological phenomena must be of the nature of a hypothesis. We can only do the best we can to frame an induction which will satisfy the major part of the demands of the phenomena. We have no direct and first-hand scientific witnesses. We have plenty of evidence of one kind and another; but it is all circumstantial evidence, and we must frame the best hypothesis we can to satisfy this evidence.

True science has never had any quarrel with *uniformity,* as a mere hypothesis. Nor can any man object to trying it out, to see if it will work. It is the most natural thing in the world, the most scientific procedure conceivable, to try to explain the geological changes of the past by the known processes now going on. But we have been trying this hypothesis for over three quarters of a century; and unless the record of the previous chapters of this book are a travesty on the real science of geology, this hypothesis has proved utterly inadequate, and must be abandoned.

Moreover, what has been said, in the previous pages, in the way of reflections against the doctrine of uniformity, has been said not against this doctrine standing alone and on its own merits, but against it in an unholy alliance with the other hypothesis of a succession of life. The latter was an absurd enough notion to begin with; but when these two ideas became united in their unholy and unscientific alliance, they became *dogmas,* not hypotheses; and for nearly a century, this pair have arrogantly domineered over the whole scientific world, as if, forsooth, they had become *laws,* and were the only explanations of the geological phenomena entitled to a hearing. But this dogmatic and domineering monopoly of the situation is now past, and another hypothesis is entitled to a candid and full hearing. All who have any judicial capacity for judging scientific evidence in an unprejudiced way are going to have a chance to estimate the relative values of these two opposed hypotheses.

As these two hypotheses are mutually contradictory, only one can possibly be true. The other must be absolutely and wholly false. Either the present is a fair measure of *all* the past, and there has been a long succession of ages under conditions much like the present; or there has been, at some

time in the past, a world change quite different from the present order of things — so different as to make unreliable any attempt to tabulate off in an accurate historical succession the events preceding this world catastrophe. If the former of these propositions is true, the latter is false; if the latter is true, the former is false. Evolutionary geology affirms the former as a working hypothesis, which, by long usage, has now become an iron dogma. The new catastrophism affirms the latter as the best explanation of the facts in sight, and asks for a reconsideration of the whole case with this hypothesis as a possible explanation. Whatever may have been the form which this issue has assumed in the past, the issue in this third decade of the twentieth century is between a dogma, called uniformity, coupled with an assumption of a supernatural knowledge of the past, called the succession of life, on the one side; and the hypothesis of a world catastrophe having overtaken a splendid world fully stocked with plants and animals. And all that this latter proposition pleads for is a full and candid hearing.

A Reconsideration Necessary. From the point of view of strict logic and scientific method, this plea for a consideration of the second alternative is reasonable; and to continue to rule that alternative out of court as unworthy of a hearing is out of harmony with the professions of a science that claims to be actuated only by a fearless search for truth, regardless of consequences. To seek to evade the issue by claiming that this hypothesis has *already* been considered a century ago and found wanting, is palpably untrue. *This hypothesis has never in the history of science had a sober and careful consideration, with a sufficient amount of evidence available to furnish the grounds for a safe and final decision of the case.* But now we do have a body of evidence on hand which is sufficient to enable us to frame a reasonably safe scientific conclusion; this hypothesis now asks for a consideration of this evidence.

Necessarily, however, this whole matter, in the last analysis, is a question of *probability,* not of mathematical certainty. There are some minds, like that of David Hume, which can say of a world catastrophe, as he said of miracles, that such a thing is impossible, and that therefore no amount of evidence can ever prove a world catastrophe. I do not expect these people to be convinced by the wonderful array of evidence which we now possess all pointing to some sort of world catastrophe as the most reasonable explanation of the facts of the stratified rocks. But for those whose minds are not dominated by the uni-

formitarian dogma, I believe that the evidence we now have will be sufficient to prove that a once beautiful world, well stocked with an amazing variety of plants and animals, was at some time in the long ago overtaken by a sudden and horrible world convulsion, the results of which we now have spread out over all the continents, in the form of the major part of the stratified deposits, and the study of which has now become the chief business of the science of geology.

A World Catastrophe. Very fortunately, we do not have to invent a hypothesis of a world catastrophe, for such a hypothesis is furnished us ready-made by the very oldest and most venerable records of the human race, to say nothing of the concurrent and harmonious tradition of every great branch of the human family. But this hypothesis is not a simple and puerile affair, as it has often been pictured. On the contrary, it is a *highly complex idea,* capable of being understood and judged of scientifically only by minds trained to weigh evidence, and by minds also willing to take into consideration a multitude of consequences or corollaries which go along with it, and without which the central idea itself can not be said to exist. Unless we are willing to examine it in detail, with all these corollaries accompanying it, we can not make any progress in the direction toward which the cumulative evidences of the previous chapters seem to point, but must remain under the same old rule of dogmatic assertion regarding the "impossibility" of such an event, and the demonstration of the evolution theory furnished by such circular reasoning as the biogenetic "law" of Haeckel, which first assumed the succession of life through geological time, and then demonstrated organic evolution by showing how the embryonic development of the modern individual corresponds to this assumed historical development of the race.

What, then, are some of these corollaries which can not be separated from the hypothesis of a world catastrophe? We shall give them in serial order, and afterwards examine them in detail, to see how they fit the evidence which is furnished us by the records of the rocks.

An Ideal World. The first corollary of this hypothesis is that regarding the character of the world with which we have to deal; for it is not the kind of world which we see now, but *an ideally perfect world,* of which the present one is but the partly salvaged ruins. In the first place, it was a world with an ideally perfect *climate.* And this means (so far as we can see) a peculiar distribution of land and water which would contribute to the making of such an ideal climate; for with all our

discussion of climate during the past fifty years, we do not seem to have hit upon any cause competent to produce an ideal climate except some particular distribution of land and water which would furnish several warm currents continually flowing into the polar regions, warming them by hot water, as it were. Along with this ideal state of climate may have existed a *peculiar salubrity of the atmosphere* which would secure a regularity of moisture to all parts of the lands, thus promoting a most luxuriant vegetation, each locality having its own special flora, and thus also, of consequence, its own particular fauna, adapted to the plant life of the locality.

The World as a Whole. Our second corollary is that this hypothesis of a world catastrophe *deals with the world as a whole,* that is, it deals with the world in its planetary aspects; and therefore this catastrophe must have been of an astronomical character, and must have an astronomical cause. In other words, to spoil this ideal world, and do it suddenly, would require an *astronomical cause,* something that would disturb this delicate equilibrium existing between water and land, thus destroying the ideal climate, and incidentally destroying the plants and animals existing upon it.

But the only astronomical cause which we can readily imagine as competent to bring about such results, would be something of the nature of *a jar or a shock from the outside,* which would produce an abnormal tidal action, resulting in great tidal waves sweeping twice daily around the earth from east to west, this wave traveling 1,000 miles an hour at the equator.

All this is but the larger setting of our picture. To descend into more minute particulars requires more uncertain inferences, though many such suggest themselves. However, without descending into more minute particulars, let us see if in these broad aspects we have anything at all corresponding to the demands of the geological problem.

The Antediluvian Climate. For those acquainted with the geological facts, there is no need of presenting evidence in favor of the earth's having once enjoyed an ideal climate from pole to pole. The corals and the coal plants of the arctic regions are objective evidence which tell a complete story that can not be misunderstood. What combination of circumstances it was which produced these conditions of an equable world-enveloping climate, may be matter for study; but that such a condition existed can no more be doubted than can the existence of Nineveh and Carthage. As it is difficult to explain this equable arctic

climate without postulating an ideal distribution and arrangement of land and water in order to bring about such a state of climate, just so the violent and sudden disturbance of this distribution of land and water could not fail to spoil this ideal climate, and probably change it suddenly and completely.

Tidal Phenomena. An abnormal tidal action would seem to be exactly what is indicated by so many evidences of an *alternation of deposits.* For instance, in the English Jurassic, there

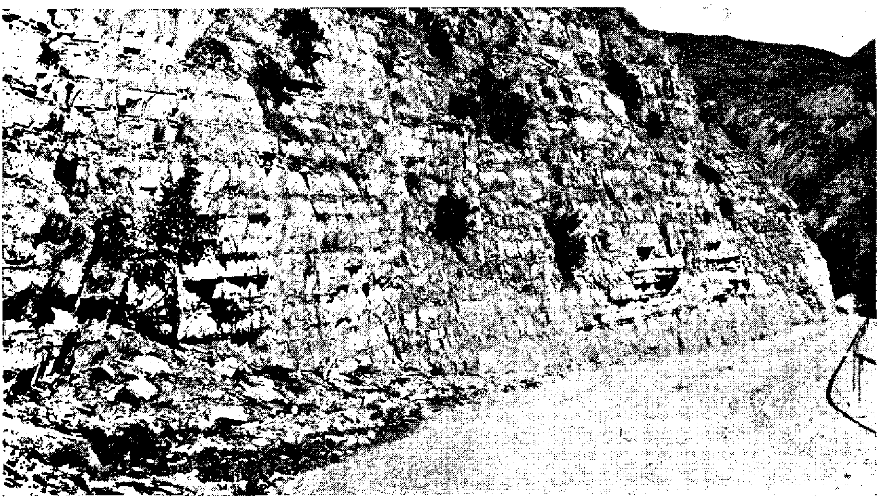


FIG. 444. "Alternations of strata of limestone and limy shale, showing rhythm in conditions of deposition." (G. K. Gilbert.) South wall of Provo Cañon, Wasatch Range, Utah. Similar rhythmic alternations are common all over the world. (Gilbert, U. S. G. S.)

is a repetition of the series, clay, sand, and limestone, one above another; and this series is repeated no less than five times between the Lias and the Portland division of the Jurassic. Almost as regularly recurrent, and on a far larger scale of repetition, are the great coal beds, where as many as 75 or 100 repetitions of the series are frequently observed. Throughout the geological series, this is one of the most common of phenomena; and it falls very appropriately within the scope of our hypothetical explanation, when we remember that every tidal action means *four movements of the waters each day,* two flows and two ebbs. And it should be remembered that any abnormal action of the tides, while it might arise suddenly, *could not subside in a similarly sudden manner,* but would necessarily be prolonged through weeks or perhaps months, with all the inevitable consequences of the ocean's repeatedly trans-

gressing over the lands, and just as repeatedly regressing from off them, and all the while performing an untold amount of geological work.

Astronomical Aspects. Let us now glance for a moment at some of the astronomical aspects of this problem.

As is well known, the earth is not a perfect sphere, but a *spheroid,* with an equatorial diameter longer by 27 miles than its polar diameter. That is, the earth has a huge solid ring around its equator. Because it is thus weighted and balanced, its axis of rotation could not possibly be otherwise than about the

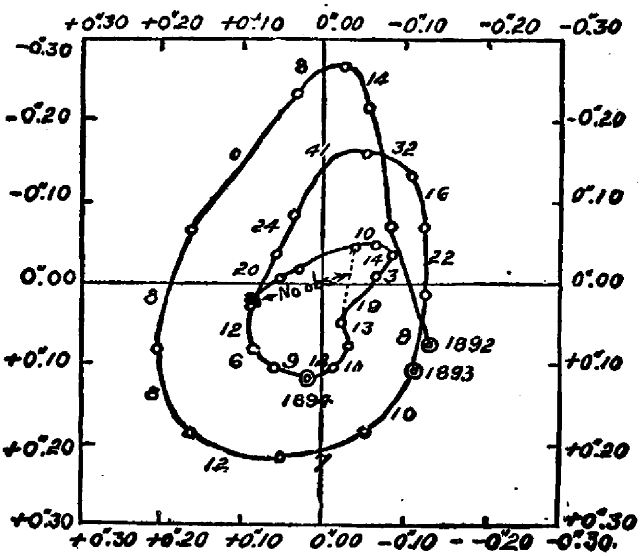


FIG. 445. Graph showing the migration of the north pole from 1892 to 1894. (After Milne.) The figures indicate the number of large earthquakes in each period.

shortest diameter, as it is now. Some have speculated that the earth was once a perfect sphere, the present difference between its polar and equatorial diameters having been brought about in connection with the other geological changes, though this seems quite improbable.

On the other hand, we know that the earth's axis of rotation is not perpendicular to the plane of its orbit, but is inclined 23½° from the perpendicular, and that the earth rolls around the sun constantly maintaining this strange inclined position. The astronomical reason for the establishment of this position is not well understood, though since it is thus established, we can not easily conceive of any cause which could change this as-

tronomical habit. To bring about any such change would require an external force, and a force of large magnitude. But if we may suppose such a change possible — that is, if the earth's axis had been formerly perpendicular to the plane of its orbit, and some external force had changed the earth to its present inclined position and changed it suddenly — there would be forces let loose on the earth's surface sufficient to do an inconceivable amount of geological work. In the first place, the earth, like a huge top, would "begin to wabble, and it would continue to wabble as a top does when going to sleep," until it had adjusted itself to its new position of rotation. (Houghton.) In the meantime, the surface of the earth would be shattered and dislocated beyond all description; and twice each day, the oceans would sweep a mighty tidal wave around the world, attaining a maximum, *every 150 days,* of about six miles in height at the equator. (Twisden.) Such translation waves, traveling at the rate of 1,000 miles an hour at the equator, and proportionately in the other latitudes, would certainly leave no dry land anywhere on earth, and would seem to give us a wonderfully competent cause for the production of the geological changes. And it is at least a remarkable coincidence that a period of 150 days is twice mentioned in the Bible account of the Deluge. (Genesis 7:24; 8:3.)

I do not affirm that this was actually the method by which the geological changes were brought about; but one can not fail to be impressed with the remarkable similarity between these astronomical calculations and the results which we find recorded in the rocks, as well as the similarity of both to the account which we have, in the Hebrew Scriptures, of the event there spoken of as the Flood.

In an earlier chapter of the present volume, we saw that there is plenty of water on the globe to cover the whole of it; that, in fact, if all the lands were submerged beneath the sea, and the solid parts all smoothed out to a uniform level, the ocean would stand at a depth of a mile and a half all over the globe. Hence the old quibble about there not being enough water on the earth to cover all the lands, is seen to be without any scientific foundation. There is enough water, and plenty to spare.

Other Considerations. But the same physical phenomena would follow, if the earth were to receive a jar or shock in appreciable strength from an outside source, such as could come from a large mass of matter falling upon one hemisphere of the earth. This would follow, partly as the mere result of the shock,

and also partly as the effect of an out-of-balance condition of the rotating body. Under such a jar, the earth would also begin to wabble, and a vast tidal wave, twice every twenty-four hours, would sweep around the earth, the amount of the earth's wabble and the size of the resulting tidal wave being *proportionate to the amount of jar or shock* which the earth had received. The period of maximum intensity for these tidal waves, given above as 150 days, would be the same for any amount of shock, small or large, provided the earth has a certain rigidity. This period has been calculated with other results; but the authority to whom I have referred above, has given it as 150 days. (Professor J. F. Twisden; *Quarterly Journal of the Geological Society,* Vol. 34, p. 41.)

Now it is a very remarkable fact that the earth does have a slight wabble at present. This is called the *wandering of the pole,* or the *variation of terrestrial latitude* (Fig. 445), by astronomers; and although it is not large at the present time, this present variation may be only the *remnant of vastly greater variations* which the earth may once have had. We can not prove this at present, but it is a very probable hypothesis.

Furthermore, we know that our modern earthquakes are largely the result of the slipping of rocks into a new position in such a way as to relieve a former tension, all such movements of the crust being of the nature of a *recovery from an existing tension,* or from an accumulating tension in the strata. And Milne has suggested that earthquakes occur more frequently and more violently whenever the value of terrestrial latitude is changing most rapidly, and possibly whenever the latitudes have reached their maximum and minimum values. In other words, this suggests a connection between earthquakes and this wandering of the pole; and it is entirely possible that this wandering of the pole, due to the wabble of the earth, may in the past have resulted in enormous geological changes.

But we must now turn to other aspects of our problem.

The Bible Record. I do not feel that any apology is needed on my part for comparing what we have already learned along these lines with the record of the Flood as given in the Bible. Personally I confess that my study of the scientific aspects of this subject has tended very strongly to increase my confidence in the Bible record; but I do not think that any intelligent person can doubt that the unanimous tradition of every great branch of the human family must represent a real and awful event which happened to the race in its early days. Hence, as this Hebrew record gives the most reasonable and intelligent

form of this narrative, it is on this account, if for no other reason, entitled to some consideration in this connection. I may myself believe that we have in this Bible narrative something of much greater importance than a mere racial tradition; yet I would never think of offering this narrative here in this connection as tending in any way to *prove* this general fact of a universal Deluge, for if anyone has attentively read the preceding pages of this book and still doubts this great general fact, neither any further words of mine nor the original record in the Bible itself would tend to convince him. But I am myself convinced of this great general fact on purely scientific grounds, and as I believe that the Bible and the book of nature have both the same Author, it would seem reasonable that that explanation is most probable which most clearly and absolutely equates these two accounts of this great event; for as already stated, the great general fact of a world catastrophe of some sort is to my mind now as firmly established as a real historical event as the reign of Hammurabi or the wars of Attila.

In considering what the Bible says on this subject, there is no need of dwelling on the words there used to express the absolute universality of the Flood; for these words are repeated over and over again. But it may be worth while to point out how, in the very prediction of the event, the declared *purpose* was to destroy the earth itself, as well as its inhabitants; that is, so to destroy the face of the earth as to make it thereafter a new world entirely. The record is, "I will destroy them [the people] with the earth." Also in the reference to this event in the second epistle of Peter, it is said, "The world that then was, being overflowed with water, perished." Evidently, if we are to take these words at their face value, the design was to make such radical changes in the whole aspect of the earth as would take away the abundant supply of food for both man and beast which had existed from the beginning, and to spoil that delightful climate which had hitherto made life in the open air a continuous joy. And no one who studies the record of the antediluvian climate which we have in the rocks, and compares that climate with the present extremes of terrific heat and death-dealing cold, can doubt that this purpose was fully accomplished.

As for the length of time occupied in the various events of the Deluge, the Bible makes very plain that it was far from being merely one huge inundation which swept over the lands and drowned the creatures living upon their surface. A few days would have sufficed to drown all the land animals; and

even all the people must have perished with but a short inundation. But the Bible record is that the Deluge really lasted more than a year. It took six weeks for the waters to attain their maximum, evidently by terrific cloud-bursts and by enormous ebbs and flows of the tides, the latter rising a little higher each day over the ever-narrowing lands, driving the men and the animals before it, until, after over a month of this agony long drawn out, those who still survived looked out from their pinnacles of mountain tops over a shoreless ocean. Then half a year or so elapsed before the waters had abated sufficiently to allow the ark to ground on the high land where it finally came to rest.

Corollaries. During all this time, an inestimable amount of geological change must have been taking place, as the waters of the transgressing oceans flowed around in unaccustomed channels and currents, doubtless swept by storms such as the world has never since witnessed. Then another half year was occupied in the process of the land's rising here and there, or (which is the same thing) by the ocean's gradually subsiding into its present basin. As we are told that the Flood began about the beginning of our northern winter, this retreat of the ocean from the lands must also have taken place at about the commencement of another northern winter. And what a winter that must have been!

For we must remember that the whole body of the ocean water originally must have been *warm*, about as warm as the surface waters of the tropics are at present. It would begin to cool very rapidly in the northern latitudes; but so long as any material amount of this original warmth remained in the ocean water, *the warm parts would float as a layer on top*. And as this warm layer came in contact with the icy cold air, the inevitable result would be to cause dense fogs and almost continuous precipitation. How long a time would be required for the waters of the ocean to cool off, it would be impossible to say. The bottom waters of the Mediterranean and of other similarly land-locked basins are *still much warmer* than the depths of the ocean — even yet, as it seems, retaining some of their original warmth, because they are so situated as to be protected from the cold currents flowing along the bottom of the oceans from the refrigerating plants at either pole. But until the great body of the ocean had appreciably cooled down to somewhat near its present temperature, there must have been *very much more precipitation* in all the northern lands than we now see. This may have taken years or even centuries.

Another great fact must not be overlooked in this connection. As has been pointed out in a previous chapter, a considerable portion of the earth's surface is *basin-shaped,* with interior drainage; that is, the water drains into hollows surrounded by hills or mountains, and this water never runs out toward the sea, but stands or evaporates where it is. The amount of the earth's surface thus occupied by these interior basins has been variously estimated at from a fifth to a fourth of the entire land surface of the globe. But the point of interest for us is that after the Flood, all these basins must have been *full of water to the very brim.* Doubtless many large basins which now have outside drainage, like the basin of the Great Lakes of North America, contained much more water than at present, the water in them standing at a higher level then, until the outflow had cut down a channel for itself more like that which we now see. But for years, perhaps for centuries, as these great interior basins remained more or less full of water, and as the perpetual banks of clouds prohibited the sun from warming the northern lands, immense quantities of snow and ice must have accumulated on all the high mountain ranges, perhaps even on some of the higher table-lands of the more extreme latitudes. In this, we have an easy explanation of all those evidences of extended *glacial action* which we see in all our mountain regions; while in the thick ice which must have formed over such waters as the Great Lakes at their former high levels, and also in the shore ice which must have formed around all the epicontinental waters as they first retreated slowly from off North America and Europe, we probably have the true explanation of at least many of those evidences of supposed glacial action with which we have been regaled for the past half century or so.

A Candid Examination Demanded. It is nothing short of a burlesque on the Bible account of the Deluge to represent it as a small, very temporary affair, which could not have performed or have left behind any extended geological work. If we are going to consider the Bible record at all, *let us give it a fair and candid hearing.* This record is not ambiguous, nor difficult to understand. From it we would gather a picture of a complete change in both the climate and the surface features of the world. Doubtless the rivers and the oceans did some geological work in that orderly, quiet world before the Flood. In our modern world, too, a considerable amount of geological work of one kind and another is being done. But all of both these series of geological operations, though prolonged over thousands of years as they have been, sink into insignificance when com-

pared with those vast changes which took place during and immediately subsequent to the world catastrophe which the Scripture calls the Flood.

Natural Consequences. We can also now understand why the marine invertebrates are, as a general rule, found in the lower strata of the earth, and why the larger animals, and especially the land mammals and such great reptiles as the dinosaurs, are usually found in comparatively superficial deposits. We can also understand why some of the Paleozoic and even some of the Mesozoic rocks are spread out in such wide sheets, often a hundred or even several hundred miles in extent, and why the Tertiaries, or the superficial deposits, are usually so fragmentary and in such interrupted patches here and there. Evidently most of the former rocks were formed near the beginning of the diluvial changes; while the latter were more generally formed near the close, or as the waters were retreating from off the lands — some of them possibly *years or centuries afterwards.* In this sense, there are *obvious chronological differences* between the older fossiliferous rocks and the younger ones; but these distinctions do not at all correspond to the present popular distinctions based on the fossils.

It is equally evident that the convulsions which the crust of the earth went through during this prolonged disturbance, would account for much of the contortion and twisting that the older rocks plainly exhibit. The friction attending some of these movements must have generated a prodigious amount of heat within the Archæan rocks; this heat would be communicated to the overlying wet strata, *metamorphosing* them, in some instances actually melting the rocks, both old and new; then further movements of the crust would often squeeze this semiliquid material out upon the surface of the earth, or perhaps on the rocks at the bottom of the sea, again to receive a deposit of sediment from the embroiled waters.

Some of the heat thus generated, also the heat produced by later chemical action, would occasionally be communicated to some of the vast carboniferous beds buried deep beneath other sediments; or these carboniferous beds would themselves take fire, and thus many genuine volcanoes would be started here and there all over the earth within a short period after the Deluge had subsided. In all this, we would have a good explanation of why volcanic action was much more abundant and possibly more violent in the long ago than at the present time.

It would be almost inevitable that enormous thicknesses of strata would be piled up over very unequally stable foundations.

And where the basement rocks were not competent to support a mile or so in thickness of extra load, these strata would necessarily settle down, while other large areas might remain nearly horizontal. Accordingly, where certain portions, perhaps a square mile or more in area, settled down because of a yielding foundation, the upper strata near the edges of this area would become tilted; and if the settling was extensive and the overlying strata was a mile or so in thickness, this tilting of the strata might result in a very marked contortion of the disturbed portions, or even in a distinct rupturing of the surface rocks. Synclines and anticlines would thus be produced all over the earth. If now a strong current of water, either marine or continental, were brought to bear upon these rocks, an immense amount of erosion would of necessity take place in a very short time.

Again, if a very great depth of strata had been piled up in a certain area, and a deeply cut channel of erosion had taken away a portion of the deposit to the depth of a mile or so before the mass had completely consolidated, as might easily occur, there would necessarily be a settling of the pile of rocks left standing; for nothing but firmly consolidated rocks at the bottom could possibly support a weight of a mile or more of superincumbent rocks. That is, when the lateral supports of the pile were removed, the pile of strata would settle or collapse.

When we understand that these things were taking place in many parts of the earth at the same time, there is little doubt that we have here an explanation of a great many things which we observe in almost every mountain region; for the rocks everywhere present the clearest evidence that most of the folding and tilting of the rocks occurred while the beds composing them were *still soft*. This physical evidence has been doubted; because evolutionary geologists have taught that the various rocks composing any considerable pile of strata were deposited slowly and through many long ages, and it has been thought incredible that the lower rocks could have remained soft and unconsolidated until after the uppermost beds had been deposited. But in view of the conditions which we have here presented, it is evident that we are now at liberty to believe the obvious indications that these strata were still in a plastic condition when their deformation took place.

The New Catastrophism. It would thus appear that we have now reached a rational explanation of all the great outstanding geological phenomena. Still, to find objections to this explanation, and to point out how in one point or another it supposes

impossibilities, will be easy enough. As one stands on the brink of the Grand Cañon, or looks down at the seething torrent at the base of a Niagara, or gazes at the lone spires of splintered rock rising through the thin upper air on any mountain top, there are very many phenomena which seem beyond the reach of any explanations we may offer. I am not insensible to such an appeal. I quite sympathize with anyone who stands dazed at the magnitude of the processes represented in any of these phenomena, and at the length of time necessary to explain them on the basis of the present action of the forces of nature. But I have scant sympathy with anyone whose mind is so constructed that he can go on complacently teaching the same old doctrinaire theories regarding the precise kinds of animals which lived in a certain age of the world, and who can continue to construct genealogical trees of descent for the horse, the elephant, the camel, and what not, in view of the evidence which is now at our disposal.

We may not have a scientific explanation of all the geological phenomena. We shall probably improve our understanding of many points with further discoveries. But the present explanation is so far superior to any hitherto offered, that it seems to me the only one worthy of the time and attention of fact-loving men and women. Future discoveries may amend and clarify some of the details of this hypothesis of the new catastrophism. They are not likely to require any material change in its essential features.

CHAPTER XLII

The Origin and Antiquity of Man

Man Created. It was Sir William Dawson, president of McGill University, who once said: "I know nothing about the origin of man, except what I am told in the Scripture,— that God created him. I do not know anything more than that, and I do not know of anybody who does."

Sir William Dawson was a scientist, a geologist; and what he said in these remarks was said by him as a scientist, and was meant as the essence of his contribution to the discussion, then acute, regarding the origin of man. To-day the center of the discussion has shifted considerably. It is now not so much the origin of man, as the *antiquity* of man, which is under discussion. Nobody knows anything more about the real origin of man than was known in Dawson's day; so this part of the problem suggested by the title of this chapter might very well be left just there. Plenty of speculations are being published in ponderous, scholarly-looking books; but of real scientific information regarding this matter, we are exactly where this great scientist declared he was — we know only that God must have created man.

Antiquity. But the second part of this subject will demand a more extended statement; for a great deal of scientific information on this point is commonly supposed to have been accumulated within recent years. Two large books, "The Antiquity of Man," by Professor Arthur Keith, and "Men of the Old Stone Age," by Dr. Henry Fairfield Osborn, may be taken as typical of a large amount of literature which has been issued within recent years, professing to prove a far greater antiquity for the human race than used to be thought possible. And the general implication seems to be that, *by pushing the history of mankind back far enough into the shadow, we can dispose of the problem of origin;* for on the strength of this seeming great antiquity, but without any adequate proofs, we are treated to numerous positive assertions that man doubtless originated from some animal stock by some process of natural development or evolution.

Various archæological human remains are depended upon by these authors to prove the great antiquity of man, and to imply an animal ancestry. Among these fossil remains of man, four specimens are the most famous: the Java skull, the Heidel-

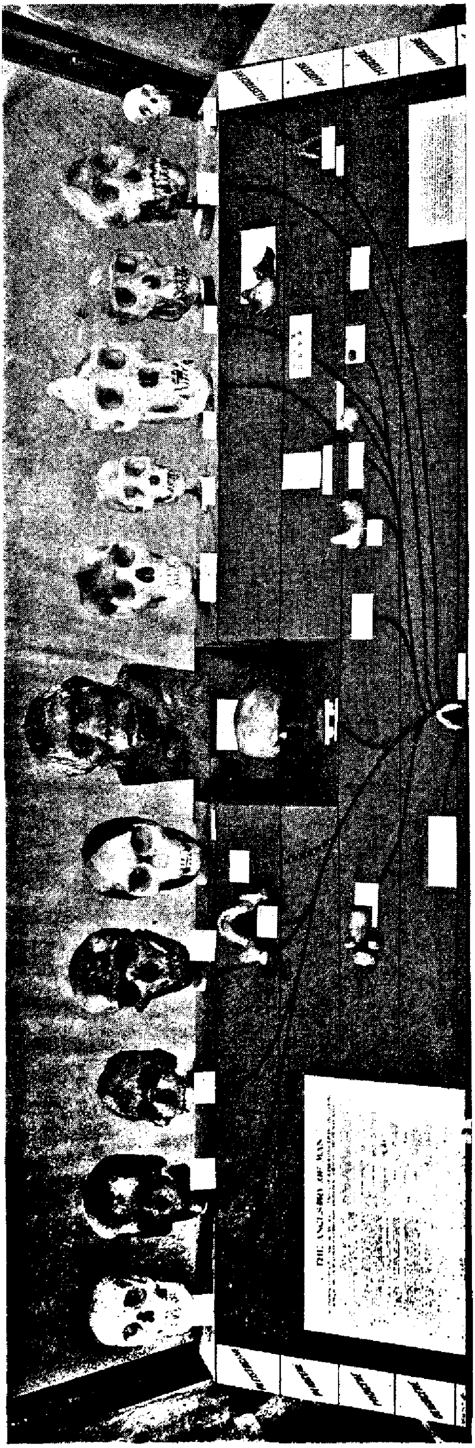


FIG. 446. A serial but artificial arrangement of some skulls of apes and men, designed to teach the ape origin of man. The fragments on the sloping foreground show the real original specimens from which these skulls have been "reconstructed." One might just as well schematize or arrange in serial order samples of the houses of New York or Boston, and claim that such a series illustrates the evolution of the American house. (American Museum of Natural History, New York City.)

berg jaw, the Piltdown skull, and the Neanderthal skull; and these are regarded as the oldest human remains yet discovered. Accordingly, it will be in order for us to consider what we know about these ancient human remains, and what light they throw on this problem of the origin and antiquity of man.

Pithecanthropus Erectus

In the year 1891, Dr. Eugene Dubois, a Dutch army officer, found the upper part of a skull and a molar tooth on the left bank of a stream near Trinil, in Central Java. The next year, a left femur, or thigh bone, was found about 45 or 50 feet away; also a second molar tooth. Still later another tooth was found. The locality was one where numerous fossil bones of animals had been found previously, and where others have been found subsequently; and the deposit from which they were unearthed has

been classed variously as Pliocene or as Pleistocene. We have already learned something of the high scientific accuracy (?) of these distinctions. Only the cap of the skull was found; and to "reconstruct" the entire skull from such a fragment in a way which makes the results reliable, is admittedly very difficult. But

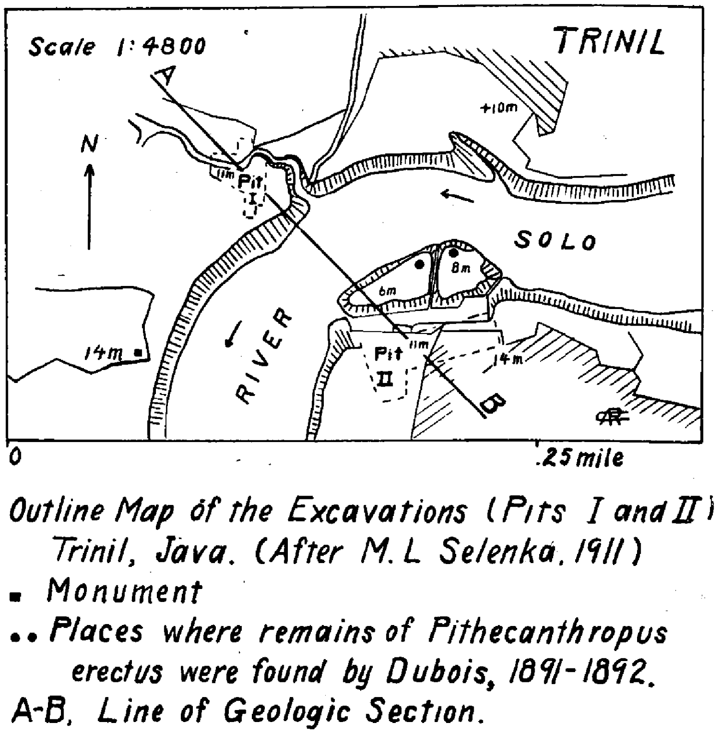


FIG. 447. Map of locality where the remains of *Pithecanthropus erectus* were discovered. (American Museum of Natural History, New York City.)

this skull is of a very low order, the capacity having been estimated as probably about 28 ounces. The average human brain has a capacity of about 49 ounces, and no normal brain is less than 30 ounces. The Java skull has been variously pronounced as that of an idiot, that of a sub-man or an ape-man, or that of a large *Hylobates*, or gibbon.

When these remains were first brought to Europe, they were shown before the third International Congress of Zoölogists in Leiden, in September, 1895. Dr. Rudolf Virchow, for thirty years president of the Anthropological Society of Berlin, and by all odds the most prominent archæologist and

pathologist of his time, was president of this congress at Leiden; and at the close of the remarks of Dr. Dubois, he criticized the latter's report by saying there was no certainty that all these bones were really parts of the same individual. He further declared that it could not be known positively whether they were the remains of a man or an ape. Later, after he had had an opportunity of examining the remains more closely, he expressed his decided opinion that the skull was that of a large gibbon. The teeth, he said, were more apelike than human; while the thigh bone, though much like that of a man, would also pass for that of a gibbon, as the latter is the only one of the apes which

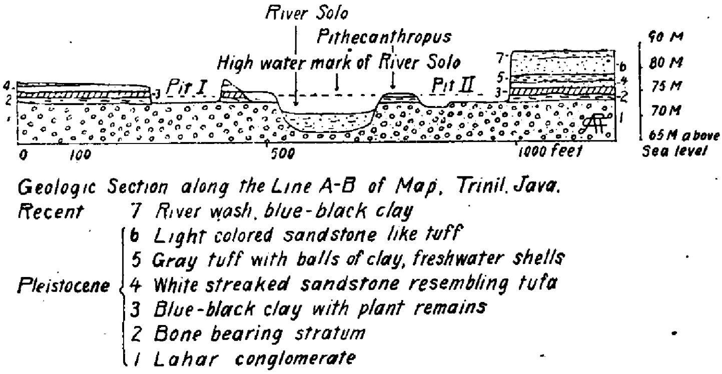


FIG. 448. Geologic section across the Solo River at the point where the skullcap of *Pithecanthropus* was discovered. Note that the river, at high water, overflows this point. This same layer has yielded many bones of mammals, some apparently belonging to modern species, though this bed is usually classed as Pliocene-Pleistocene. (After Osborn.)

habitually walks in an upright position, and there is a very marked resemblance between its femur and that of man.

This opinion that these bones really represent a gibbon, is concurred in by some of the very foremost scientists. For example, Richard Hertwig says, "The opinion that is most probably correct is that the fragments belonged to an anthropomorphic ape of extraordinary size and an abnormal cranial capacity, and with a relatively large brain."

Only the large size seems to stand in the way of anyone's regarding it as the remains of an ape. Macnamara, after careful study of the specimen, declared that Pithecanthropus was a true ape of rather extraordinary size. He says, "The cranium of an average adult male chimpanzee and the Java cranium are so closely related that I believe them to belong to the same family of animals, that is, to the true apes." This opinion is also

indorsed by many German authorities, including Klaatsch and Branca, the latter being professor of geology and paleontology in the University of Berlin. And as we are accustomed to find among the true geological deposits specimens of animals which are larger than the corresponding modern specimens, I do not see why any mere question of size should hinder us from classing these remains as those of a prehistoric gibbon.

In an article in a recent number of the *North American Review* (April, 1922), Dr. W. H. Ballou bluntly throws doubt upon the *bona fides* of the discoverer of these Java remains, because of the fact that Dr. Dubois sealed up these remains some forty years ago, and has since never allowed any scientists to examine them. Furthermore, Dr. Dubois has recently announced that forty years ago, or at the same time at which he discovered *Pithecanthropus,* he also secured other skeletons, of other prehistoric men and women, with skulls much larger than those of any known race. This long-delayed announcement does not tend to quiet the natural suspicions aroused at the fact that the discoverer will not even yet allow other scientists to examine his specimens.

This specimen from Java is always spoken of as by all odds the oldest relic of humanity yet discovered. But the geological age of the bed in which it was found, is far from being satisfactorily established; and this skull may not be of true geological age after all. Moreover, it seems quite probable that these remains do not represent a human being, but rather a large ape. Hence we can not think that this particular "find" helps us very much in regard to the problem of man's antiquity.

The Heidelberg Jaw

In 1907, there was found in a sand pit at Mauer, near Heidelberg, Germany, a human mandible, or lower jaw, containing some teeth. The stratum in which it was discovered was about 78 feet below the surface, some 24 distinct layers having been counted in the entire deposit above it. These strata have been identified geologically as corresponding to the so-called "forest bed" of Norfolk, England, classed as "pre-Glacial."

The front teeth, including the incisors, canines, and premolars of this jaw, are pronounced by Professor Keith to be of the same shape as those of the specimen found at Spy, which will be referred to later. That is, these teeth are of practically normal pattern, and are not of extraordinary size. But the jaw itself is so massive, at least its ascending ramus is so large, that this characteristic seems to place this jaw almost in a

class by itself. At least, this is the argument. The crowns of four of the teeth had been broken off by accident; the rest of the teeth were intact. No distinct chin is recognizable in the jaw. Subsequently what are called "eoliths," or fragments of sharp stones said to have been manufactured by human beings, though of little regularity of form, were discovered in the same sand bed, some distance away.

This jaw evidently does not shed much light on our problem. This specimen is doubtless quite old — but just how old, or even relatively how old as compared with any other human or animal fossils, nobody can say with any degree of certainty.

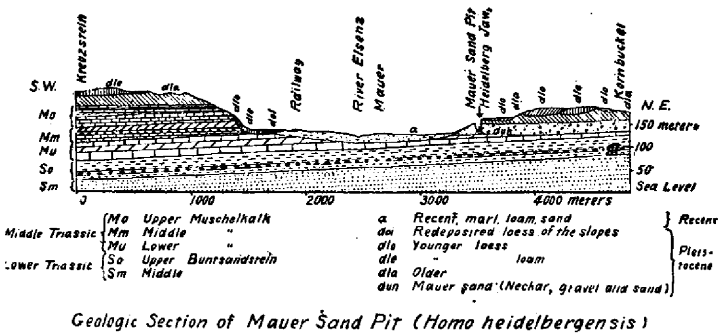


FIG. 449. Geologic section where the Heidelberg jaw was found. (American Museum of Natural History, New York City.)

Everything about the whole matter is of that delightful uncertainty which makes it an admirable subject for discussion. It is largely a matter of personal opinion.

The Piltdown Skull

The larger part of a skull, with part of a jawbone, was found in 1913 at Piltdown, Sussex, England, in a bed of gravel on a high plateau or ancient river terrace. These have been named "Eoanthropus," and have by some been declared to be the oldest human remains hitherto found in Europe. Many authorities, however, place this relic after the Heidelberg specimen.

This Piltdown skull has been restored or reconstructed by several scientists, and it is rated by some as having a capacity of about 43 ounces, or slightly below the average male skull of to-day, being almost exactly that of the average female brain, which is given as 44 ounces. The brain case is very thick, and

the fore part of the face is regarded as prognathous, or snouty; but the forehead is as steep as in modern man, and not receding, though somewhat narrow. This jaw also, like the Heidelberg one, has no chin; and its ramus, or neck, is very thick.

Professor Keith criticizes the restoration of this skull proposed by Dr. Smith Woodward, saying that when the latter came to "replace the missing points of the jaws, the incisor and canine teeth, he followed simian rather than human lines." ("Antiquity of Man," p. 324.) However, at last, Keith declares, "An approach to symmetry and a correct adjustment of parts came only after many experimental reconstructions." (P. 364.)

Considering the fact that these fragments were not all found together or at one time, some of them having been found in the autumn and the rest in the spring of the next year, the various fragments being scattered over an area of several yards, the difficulty of being sure of the real form and size of this skull will be appreciated.

As for the geological age of these remains, Keith calls them Pliocene, while Smith Woodward thinks them Pleistocene. Keith thinks the skull is that of a woman.

The Neanderthal Skull

In 1857, portions of a skeleton, including the cap of the skull, were found in the Neanderthal Cave, near Elberfeld, Germany, by Dr. Fuhlrott, who at first doubted whether they were the remains of a human being. As so many years have elapsed since this specimen was found, there has accumulated a voluminous literature dealing with it; and almost every expert from that day to this has had his say with reference to whether or not this piece of a skull takes us perceptibly nearer to our supposed ape ancestors.

Huxley declared that it was the most apelike of any skull discovered up to that time; for the three specimens which we have been studying about have all been discovered since Huxley's time. Huxley compared this Neanderthal skull with those of the flat-headed natives of Australia, and with those of other examples of what are usually called "primitive" man; but he added, "I may say that the fossil remains of man hitherto discovered do not seem to me to take us appreciably nearer to that low pithecoid [apelike] form, by the modification of which he has probably become what he is."

Huxley thought that these bones from Neanderthal were of great antiquity; but there were circumstances connected with

this case which made the matter quite uncertain. No human implements were found in this cave, nor any bones of extinct animals. These bones had not been unearthed by any responsible scientist, but by some workmen; and it appeared that these workmen had been careless in collecting them, and had preserved only the larger ones. From all that could be learned of the circumstances attending their finding, it was entirely uncertain whether the bones had been buried in this cave by friends in prehistoric times, or whether they had been washed into this place from the surface of the ground outside. As for the geological "age" represented, one man's guess is as good as another's.

Regarding the type of skull here being dealt with, Virchow unhesitatingly pronounced it a pathologic specimen; and we must remember that Virchow was the founder of the science of pathology. He further declared that he had often seen upon the streets men with just such shaped skulls as that of the Neanderthal man. Others, however, have strongly emphasized the prominent ridges above the eyes, and the very long, almost flat form of the head.

Keith says, "Although the brain of Neanderthal man equals or exceeds that of the modern type of man in point of size, yet in its general conformation it resembles the brain casts taken from anthropoid skulls." And he further adds: "We feel assured that certain features of the face [but the bones of the face are absolutely lacking and unknown to us] would have at once struck us as totally different from the corresponding features in all varieties of modern man. To find eyebrow ridges like those of Neanderthal man, great continuous horizontal bars of bone, overshadowing the orbits — a supra-orbital torus — we have again to refer to the anthropoid skull." (P. 140.)

Keith is one of those who claim that this skull should be regarded as that of a distinct race or species of man. From the scanty fragments found at Neanderthal, it would not seem reasonable to erect this specimen into a racial type; and this might indeed not have been done, but for the subsequent discovery of some more complete remains at Spy, near Namur, Belgium, in 1886. Two nearly complete skeletons, a man and a woman, were found in a grotto at a depth of about 16 feet. The skull of No. 1 of these was broken into about forty pieces, and the other also was badly broken. The jaw of No. 1 is well preserved, except in the region of the coronoids and condyles, where it joins the skull. But the lack of the latter makes only

conjectural any position in which we may place it to show its original position. Only one entire femur and the upper half of another belonging to the other specimen were recovered.

Virchow said that the characteristics shown in these skulls were still to be seen in some exceptional Friesian skulls of to-day. But others subsequently have pointed out the similarity between these specimens from Spy and the one from Neanderthal; and they have made them the foundation for a new and distinct race or species of man,— *Homo neanderthalensis,* or *Homo primigenius,* as this species is variously named. Associated with the skeletons at Spy were found bones of the rhinoceros

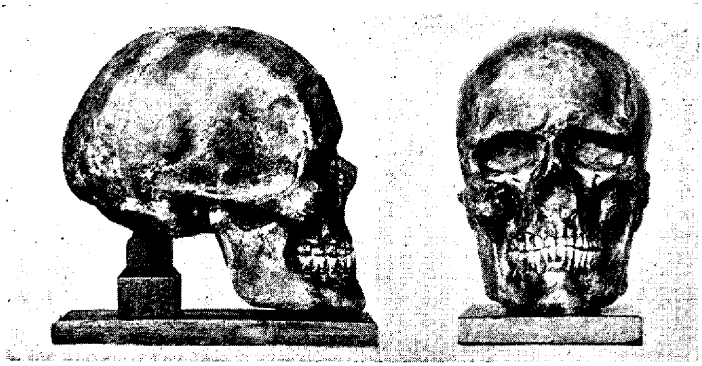


FIG. 450. Skull of the "old man" of Cro Magnon. (American Museum of Natural History, New York City.)

(*R. tichorhinus*), the mammoth (*Elephas primigenius*), and the great bear (*Ursus speleus*). A geological study of the locality where these remains were found shows that the present valley of the Orneau, the stream flowing near by, was already almost completely formed when the materials were deposited in the cave in which these skeletons were found; and from the position of the bones when found, it was evident that the bodies had been buried by friends.

Other Specimens. We have now examined all the most famous examples of human remains found anywhere in the world, the crucial ones from which evolutionists have sought to prove the great antiquity of the human race. The three skeletons found at Cro Magnon, Dordogne, France, are almost equally famous; but they are so well developed and in every way such splendid specimens of mankind that anthropologists do not

think they can really be very old — that is, in the geological sense. The skulls here are of the dolichocephalic or long-headed type, and are thus classed as distinctly paleolithic by many authorities; but the large size of the brain cavity, as well as the magnificent development of the bodies, has made other scientists insist that these men can not be as old as the smaller and more "primitive" looking ones. They are now usually classed as "Upper Paleolithic."

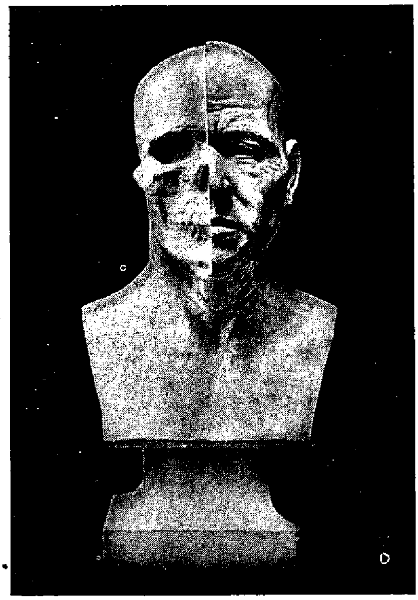


FIG. 451. Lateral restoration of the head of the "old man" of Cro Magnon. (American Museum of Natural History, New York City.)

The old man of Cro Magnon was over six feet tall, with a skull which one authority says was equal to that of Bismarck, the skeleton giving "evidence of immense muscular development." (Dawson.) He had evidently attained a great age; for, though every tooth was sound, they had been worn down almost to the very sockets. Keith declares that this race "was the finest the world has ever seen"; while Macnamara says, on the basis of these remains, that the tradition about "a race of giants in far distant times was no myth." Several of the Cro Magnon men were six feet four inches high.

But according to the rules formulated by evolutionary archæologists for estimating the antiquity of man, which will be given presently, these men of the Cro Magnon caves are not regarded as of very high antiquity. They were far too well developed, and had far too large a brain. This is the method of reasoning.

It would not serve our purpose to take up the many other examples of human remains found in various parts of Europe, or to speak of the wonderful art work found on the cave walls of Southern France. But it would never do to pass over the remarkable set of rules by which the antiquity of any human remains are judged, by those who have to deal with these matters in a professional way. The rules here given were at one

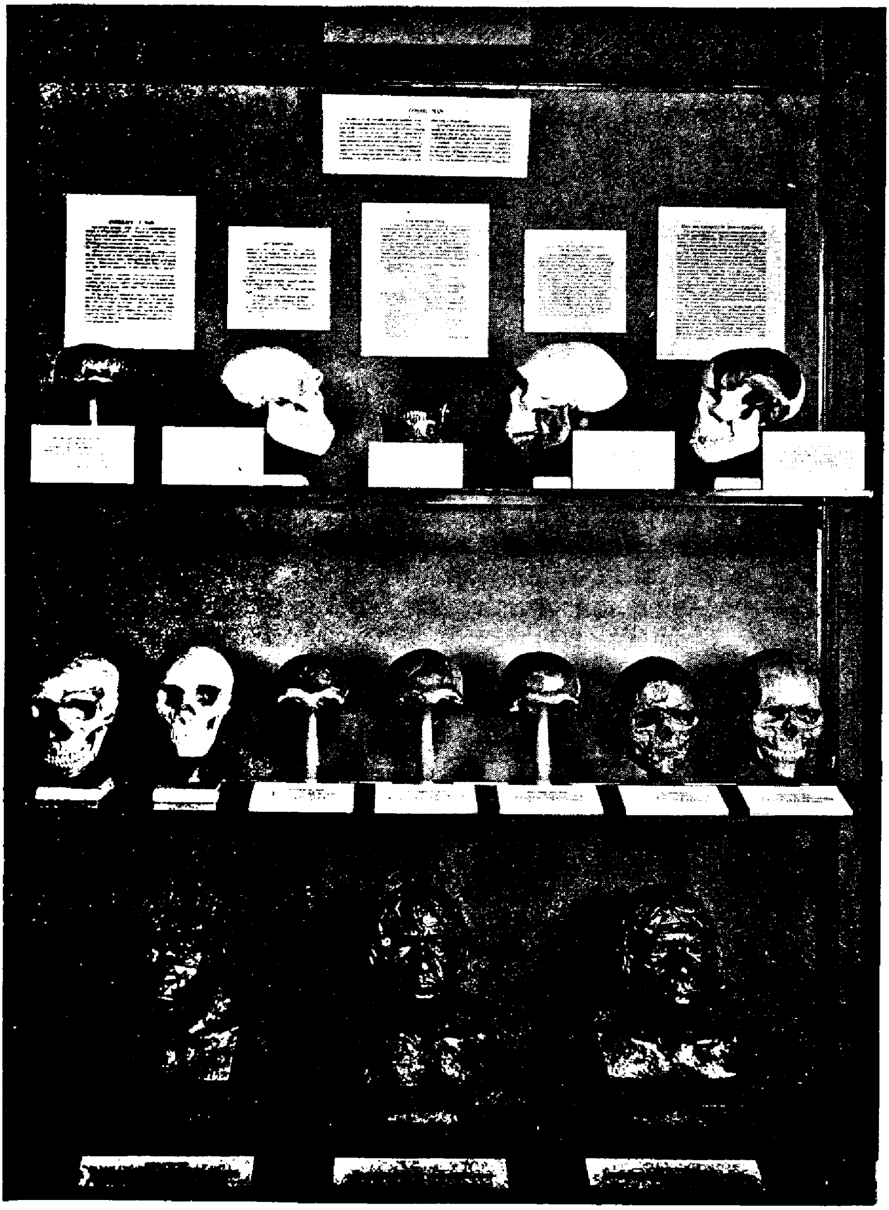


FIG. 452. Some of the most famous skulls. In the upper right-hand corner is shown the printed card stating "How the Antiquity of Man is Estimated," a full reproduction of which is given in the text. (American Museum of Natural History, New York City.)

time[1] placed conspicuously in one of the show cases containing models of these most famous human skulls, in the anthropological section of the American Museum of Natural History, New York City, of which institution Henry Fairfield Osborn is the president.

How the Antiquity of Man Is Estimated

"The dating of human skeletal remains is at best only a rough approximation. The probable error of our estimate would undoubtedly be expressed in thousands of years. Nevertheless we have several guides in determining the probable position in time of a given find.

"The first and best indication is afforded by geological records. Geologists know that the sands, gravel, loam, and loess of certain localities were deposited by glaciers, rivers, or winds during certain geological periods. Another valuable guide is the association of human remains with the skeletal remains of animals now extinct. Paleontologists have a fairly clear idea as to the time at which these animals became extinct. A third indicator is the kind of articles of human manufacture found with the skeletons. Archæologists have a general idea of the gradual development of human industries in Europe up through the exclusive use of rough stone implements, to the more finely finished products of polished stone, bone, copper, bronze, and iron. Finally the nature of the skeletal remains themselves affords an indication of their probable place in man's evolution.

"The attitude of modern science is decidedly critical, and not until a given specimen has been subjected to the above four tests is it finally assigned to a definite place in man's history. Many finds, which have failed to satisfy the demands of science on one or more of the four points of geological position, associated animal remains, associated implements of human manufacture, and morphological form, have been temporarily placed to one side to await the possibility of future discoveries throwing some light on their true position."

Unscientific Methods. This statement is as charmingly candid as it is authoritative; for evidently, according to these rules, the whole doctrine of the evolution of man from low, savage, or semi-brute beginnings is *quietly assumed to begin with,* and every evidence not in full accord with this prejudice is "temporarily placed to one side" and not allowed a hearing

[1]The writer copied them in the summer of 1920; but on a subsequent trip to New York in the spring of 1922, the card containing these rules had been removed. The card is shown in the accompanying illustration, in the upper right-hand corner of the show case.

in rating any remains which have to do with the antiquity and early history of mankind. In the light of these facts, it is not too much to say that, with our present discoveries, and under the rules now in vogue for evaluating these discoveries, it is quite impossible to arrive at any clear and accurate picture of the early days of man in Western Europe.

Personally, I do not know of a single example of a human relic found anywhere on earth which we can confidently say antedates the great catastrophe of the Deluge; though, if any such specimens should be found, *I do not see how they could get into scientific literature, if they had to run the gauntlet of such rules as those just quoted.*

But rules or no rules, I do not think anyone can say that any very ancient human remains have been discovered in the New World. As Duckworth says, "Time after time the attempts to demonstrate the early origin of man in the American continent have resulted in failure, which in some cases has been regrettably ignominious." ("Prehistoric Man," p. 55.) And it seems to me that in even those cases where human remains have been found in Europe in association with the bones of such distinctly fossil animals as the mammoth, rhinoceros, hippopotamus, and great bear, these human remains are mingled with these fossils only as they are also mingled with the rocks and bowlders which also accompany them. In other words, these fossil animal bones may be as much bowlders as the rocks; and the human remains may be altogether quite subsequent to the former, as we know they were subsequent in origin to the latter.

My reasons for making such a statement are as follows: It is evident that for a long time, perhaps for many centuries, the bones of these antediluvian animals must have been thickly scattered over and through all the soil and the entire surface deposits of great areas of the northern lands. The very fact that we find such numbers of them now, after these thousands of years, is an indication of what immense quantities must once have been found almost everywhere. Under these circumstances, it would be almost impossible for any human remains to be entombed, either by accident or by deliberate burial, without our now running the risk of finding fossils of these ancient animals in association with these human remains; but only in association with them as bowlders, like the rocks and stones. At least, I can not feel sure that in any of the cases hitherto reported, the presence of mammoth bones, or those of the rhinoceros or great bear, etc., really proves the antediluvian age of these human remains.

The Verdict of the Future. It seems to me that the discovery of genuine antediluvian human remains is still in the future. At any rate, satisfactory evidence of any such discovery has not yet found its way into orthodox scientific literature. Doubtless there are such human remains somewhere in the earth, and they may some day be unearthed; but I do not know of any examples to which we can now point with confidence as undoubtedly of the same age as that of the mammoth and the hippopotamus and the rhinoceros in England.

Here we must leave the matter for the present. Some day we may be able to learn more about that physically splendid race of antediluvian man. I say physically splendid; because, as the great mammals of that day were all such that their modern representatives of the same species "are dwarfs in comparison" (Dana), we have the most reliable of scientific reasons for expecting the *same characteristic to hold true of the men of that same time,* who were undoubtedly the contemporaries of these great land animals.

The reasons why we have not yet found any such human remains which we can confidently rate as antediluvian, are, I confess, theological rather than scientific. We are told that the Creator undertook deliberately to destroy that ungodly race; and we can only suppose that He accomplished this work in a complete and satisfactory manner, and that He buried their remains so completely that we have not yet found any of them.

But it may not be inappropriate to conclude these studies with the remark with which we opened this chapter, words from one of the greatest and most reverent of the students of the rocks:

"I do not know anything about the origin of man, except what I am told in the Scripture,— that God created him. I do not know anything more than that, and I do not know of anybody who does."

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